NATIONAL ENERGY TECHNOLOGY LABORATORY

Gasification System Title

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U.S. DEPARTMENT OF ENERGY

Slide Library

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Gasification 101

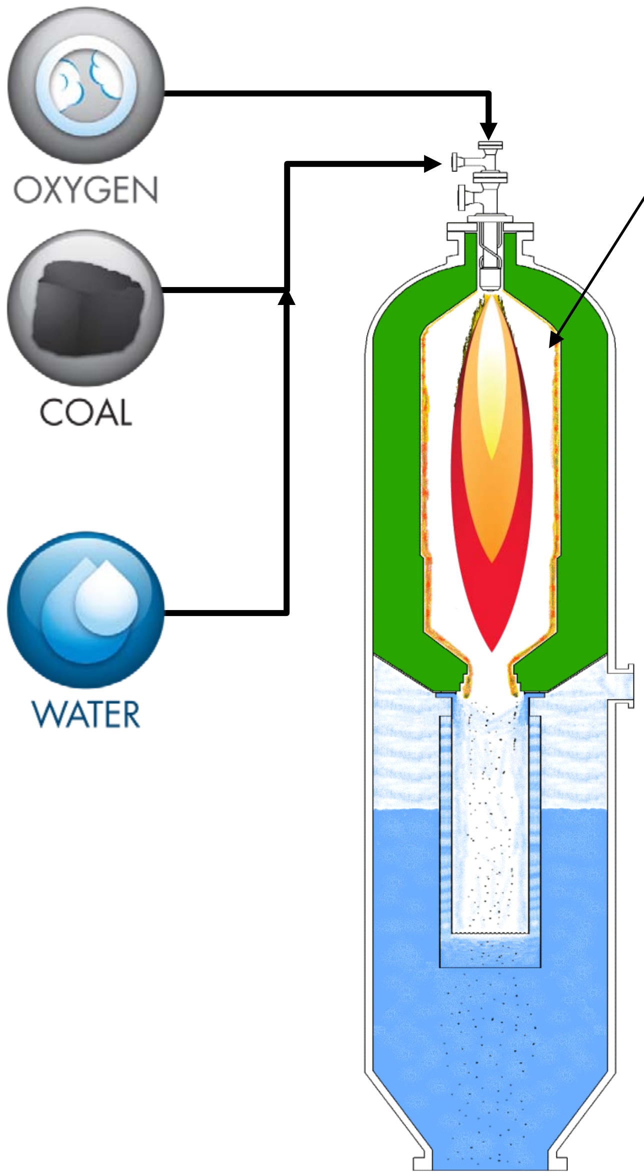
What is Gasification?

Gasification converts any carbon-containing material into synthesis gas, composed primarily of carbon monoxide and hydrogen (referred to as syngas)

Syngas can be used as a fuel to generate electricity or steam, as a basic chemical building block for a large number of uses in the petrochemical and refining industries, and for the production of hydrogen

Gasification adds value to low- or negative-value feedstocks by converting them to marketable fuels and products

The Gasifier



Extreme Conditions:

415 psia or more
2,600 F
Corrosive slag and H_2S gas

Products (syngas)

CO (Carbon Monoxide)
H_2 (Hydrogen)
[CO/H_2 ratio can be adjusted]

Gas Clean-Up before Product Use

By-products

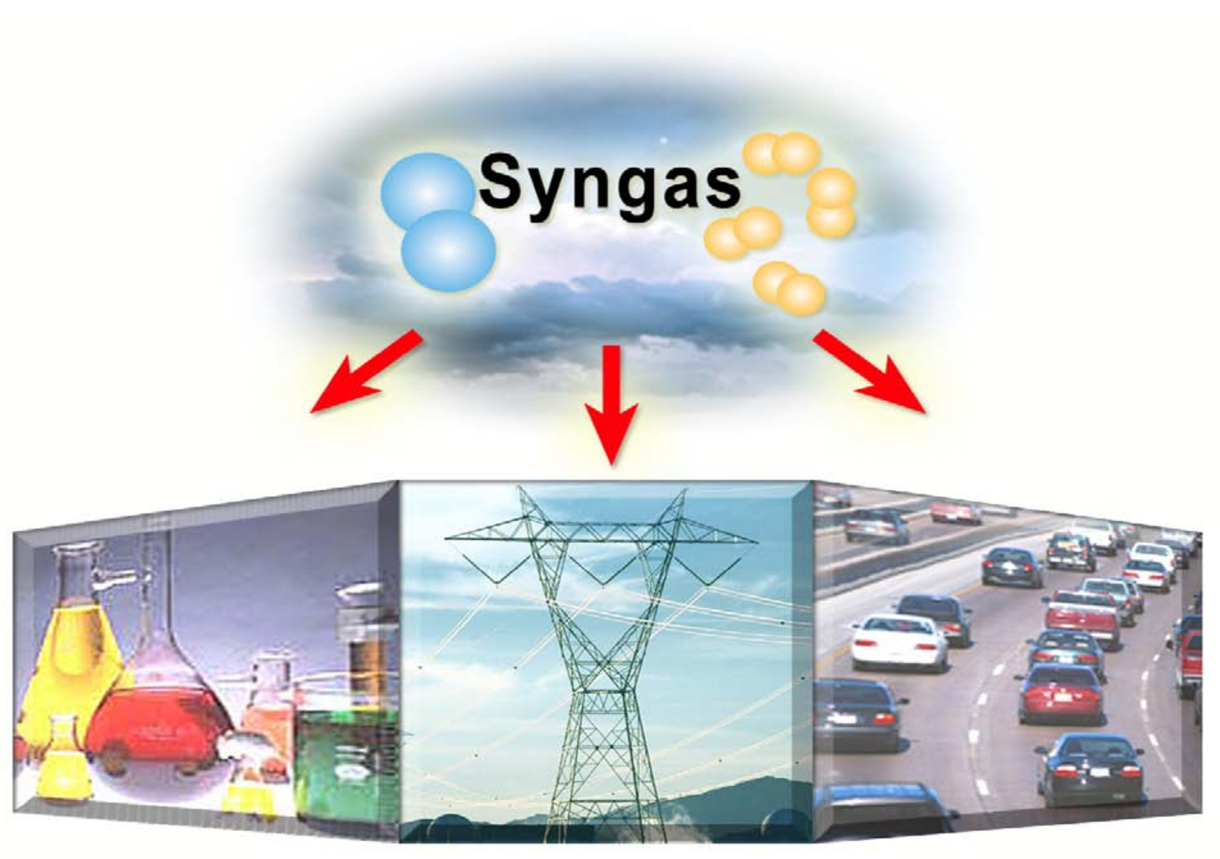
H_2S (Hydrogen Sulfide)
CO_2 (Carbon Dioxide)
Slag (Minerals from Coal)

Courtesy: Eastman Chemical

Gasification – Differences from Combustion

- Add water and high pressure
- Use less air or oxygen
- Gasification exit gases are at high pressure, so smaller volume, smaller reactors
- Combustion makes heat + CO_2 + H_2O
- Gasification makes less heat + carbon monoxide + hydrogen ($CO + H_2$); called Syngas

So what can you do with CO and H_2 ?



Building Blocks for Chemical Industry

Clean Electricity

Transportation Fuels (Hydrogen)

Water-Gas-Shift (WGS) Reaction

Dry syngas is ~ 40% CO + 50% H_2

For each CO molecule the WGS reaction creates one H_2 molecule and one CO_2 molecule

$$CO + H_2O + \textit{catalyst} \longrightarrow CO_2 + H_2$$

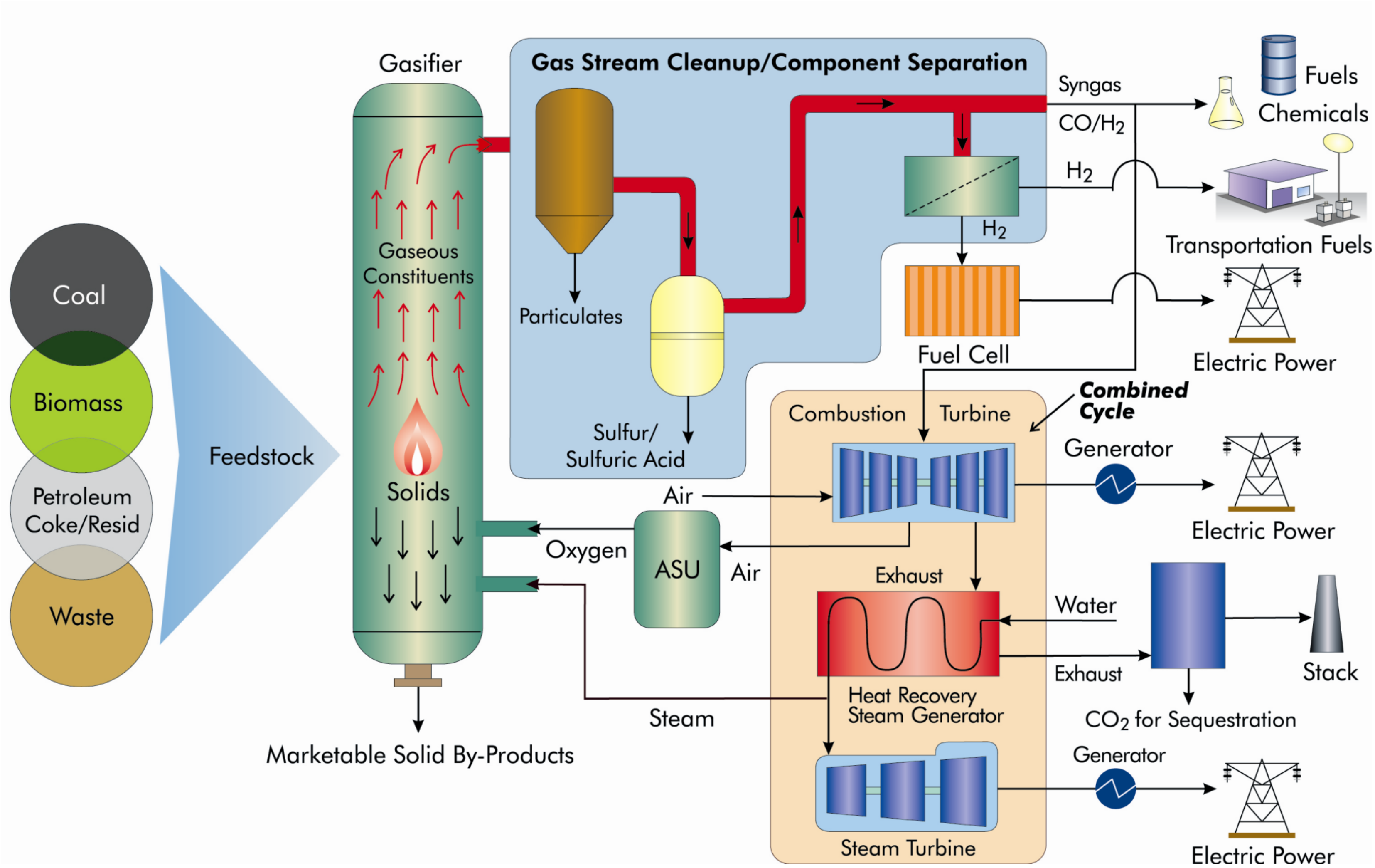
After the WGS reaction, the CO_2 and H_2 can be separated

High pressure CO_2 results in lower cost sequestration

Hydrogen can be burned to make power

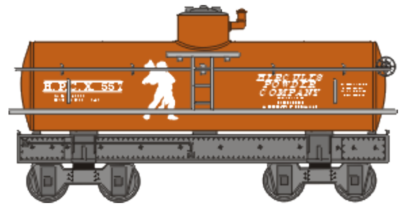
$$2H_2 + O_2 \longrightarrow 2H_2O$$

Overview of Energy Systems Options



Chemicals and Products from Gasification

Syngas



Acetic Anhydride
Acetic Acid

Methanol

Ammonia

Fertilizer (Urea)

Liquid Fuels (Diesel)

Hydrogen

Courtesy: Eastman Chemical

Benefits of Gasification

Feedstock flexibility

Wide range of coals, petcoke, liquids, wastes, biomass can be utilized

Product flexibility

Syngas can be converted to high valued products: electricity, steam, hydrogen, liquid transportation fuels, chemicals, SNG

Environmental superiority

Pollutants can be economically controlled to extremely low levels (SO_2, NO_X, CO, Hg, etc.)

Reduced water consumption

Potential solid wastes can be utilized or easily managed

High efficiency / low CO_2 production

CO_2 can be easily captured for sale or geologic storage (sequestration)

Program Slides

Why the Interest in Coal Gasification?

Continuing fuel price fluctuation – natural gas and transportation fuels

Energy security – the U.S. has a lot of coal

Gasification can be used to make hydrogen (H_2), fertilizer, chemicals, transportation fuels from coal

Can be the lowest cost option to make power with carbon dioxide (CO_2) capture and storage

Excellent environmental performance for power generation

Gasification Systems Program Goal

The goal of the Gasification Systems Program is to reduce the cost of electricity, while increasing power plant availability and efficiency, and maintaining the highest environmental standards

"Federal support of scientific R&D is critical to our economic competitiveness"

Dr. Steven Chu, Secretary of Energy
November 2010

Gasification Systems Program

Focus to reduce the cost of gasification, while increasing plant availability and efficiency, and maintaining the highest environmental standards

FE Program Target: IGCC with CSS that has less than 10% increase in COE and 90% capture

Increasing focus on low rank coal (LRC) gasification

EIA forecasts significant growth in western coal production; low rank western coal cost per Btu predicted to remain at about half that of eastern coal

Industry interest in cost-sharing LRC R&D

Potential for economic boost to U.S. regions with LRC reserves

Gasification Systems Program

Key Technologies

Feed Systems

Oxygen separation

Expand fuel flexibility

Increase efficiency

Gasifier Optimization and Plant Supporting Systems

Improve reliability

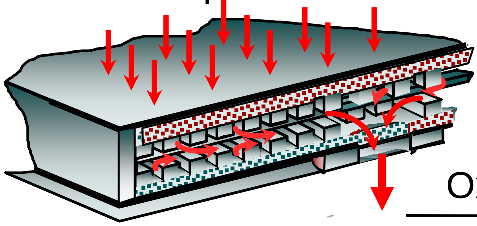
Increase efficiency

Syngas Supporting Systems

Hydrogen and carbon dioxide separation

Control multi-contaminants to extremely low levels

Key Gasification Systems R&D Areas

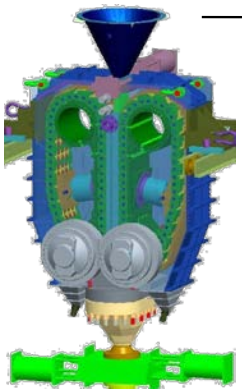


Oxygen

Feed Systems

- Oxygen separation
- Expand fuel flexibility
- Increase efficiency

Feedstock



Raw fuel gas

Syngas Supporting Systems

- Control multi-contaminants to extremely low levels
- Separate CO_2 from hydrogen

Clean fuel gas

Water Gas Shift

H_2 rich stream

CO_2

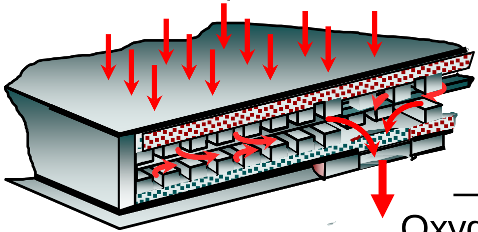
Gasifier Optimization & Plant Supporting Systems

- Improve reliability
- Increase efficiency

Gasification Systems Projects

Anticipated Benefits

Hot Compressed Air



Oxygen

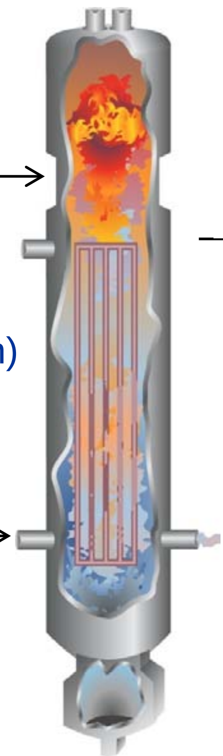
APCI Oxygen Membrane

- 6.9% capital cost reduction (36.0% O_2 plant capital cost reduction)
- 5.0% COE reduction

Feedstock

PWR Coal Feed Pump

- 1.0% COE reduction



Raw Fuel Gas

Clean Fuel Gas

RTI Warm Gas Cleaning

in combination with

Eltron H_2-CO_2 Membrane

- 2.6 % pt efficiency increase
- 12.0% COE decrease

Water Gas Shift

- Process improvement and intensification

H_2 Rich Stream

CO_2

Low-rank Coal

Alternative Feedstocks

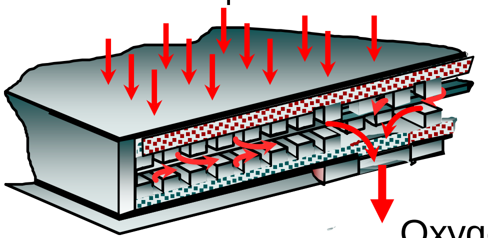
- Energy security
- Carbon footprint reduction

Improvements in Reliability, Availability, and Maintainability

- Syngas cooler plugging and fouling mitigation
- Plant availability and total cost improvement studies
- Refractory durability
- Heat removal/integration
- Temperature control and measurement
- Dynamic simulator
- CFD gasifier modeling
- Slag model development

Gasification Systems Project Benefits

Hot Compressed Air



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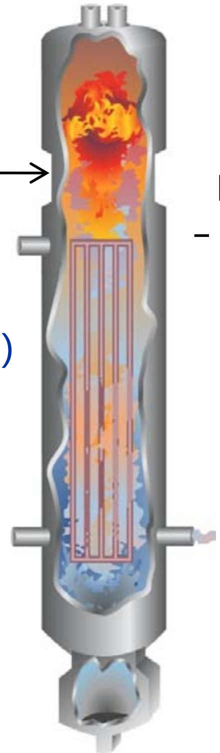


Raw Fuel Gas

Clean Fuel Gas

Water Gas Shift

NCCC WGS Optimization

ORD Pd Sorbent

RTI Warm Gas Cleaning

in combination with

Eltron H_2-CO_2 Membrane

- 2.6 % pt efficiency increase
- 12.0% COE decrease

H_2 Rich Stream

CO_2

Low-rank Coal
Alternative Feedstocks
Goal is competitive use of LRC

Improve RAM
Goal is 10% Improvement

Low Rank Coal Program Pathway

Why It's the Right Time

Gasification industry interviews show interest in low rank coal

Most projects are cost shared with industry

Industry use is objective of Gasification Program R&D

Low rank coals present unique challenges *and* opportunities for gasification and IGCC

High inherent moisture, high in alkali metals (Na, K, Ca)

High oxygen content, high reactivity, low sulfur and <u>Low Cost</u>

NETL systems analysis has shown low rank coal gasification has the potential to be economically competitive

Altitude vs Shipping

Limited gasifier types

About half of the world, and U.S., coal reserves are low rank – a global market opportunity for advanced IGCC technology

U.S. Low Rank Coal Resources and Prices

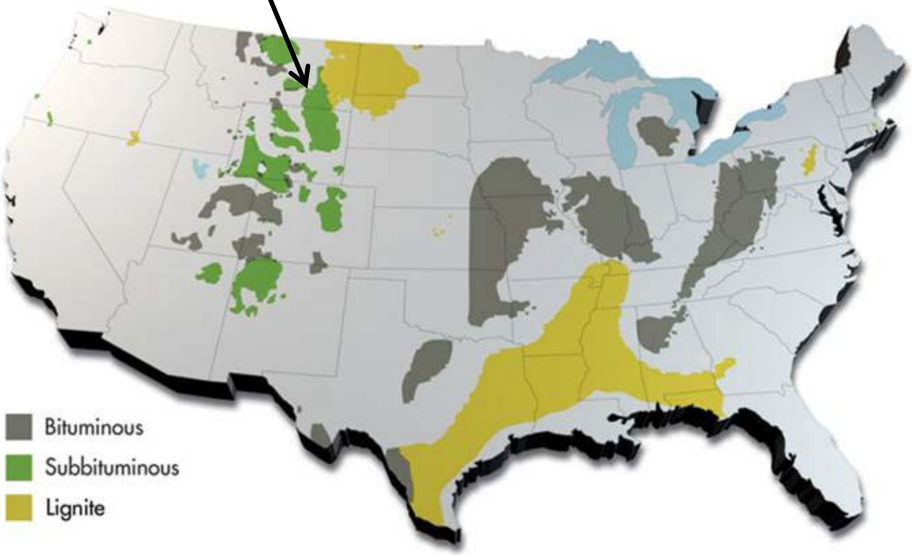
Low rank: lignite and sub-bituminous coal

About 50% of the U.S. coal reserves

Nearly 50% of U.S. coal production

Lower sulfur

Year	Lignite Price ($/ST)	PRB Price ($/ST)	Bitum. Price ($/ST)
2010	16.77	13.93	53.40
2011	16.41	13.15	51.87
2015	16.67	13.00	48.70
2020	17.31	13.92	48.23
2025	17.83	15.31	49.03



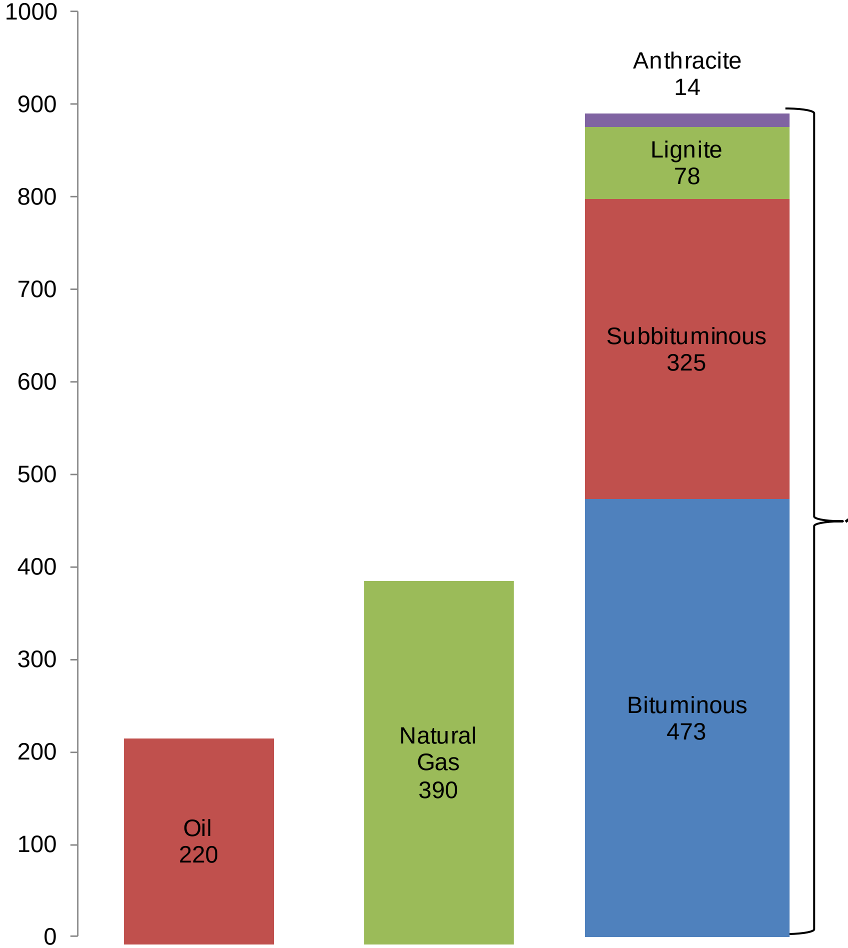
EIA forecasts significant growth in western coal production; declining eastern coal production

Low rank western coal cost per Btu will stay at about half that of eastern coal

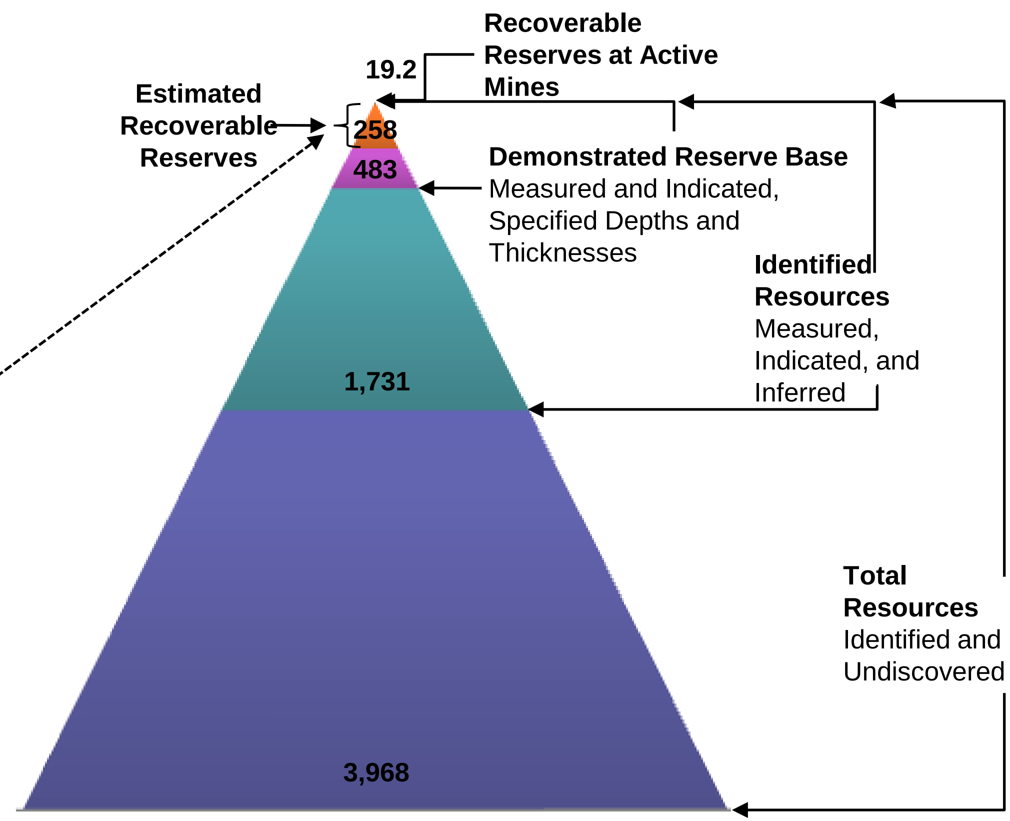
Energy Outlook

U.S. Fossil Fuel Resources

U.S. Fossil Fuel Reserves
billion barrels of oil equivalent



U.S. Coal Resources
billion short tons

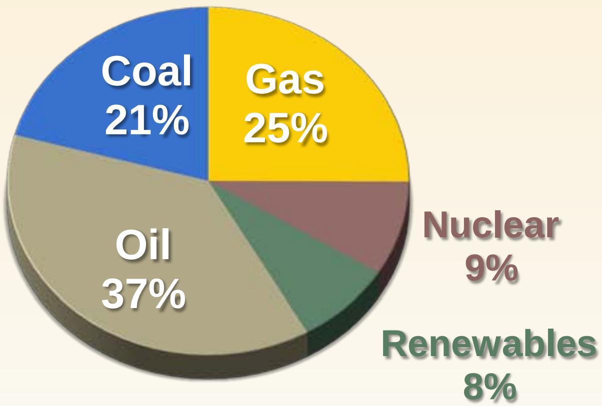


U.S. Energy Information Administration, ***Annual Energy Review,*** *September 2012*

Energy Demand 2009

Energy Demand 2035

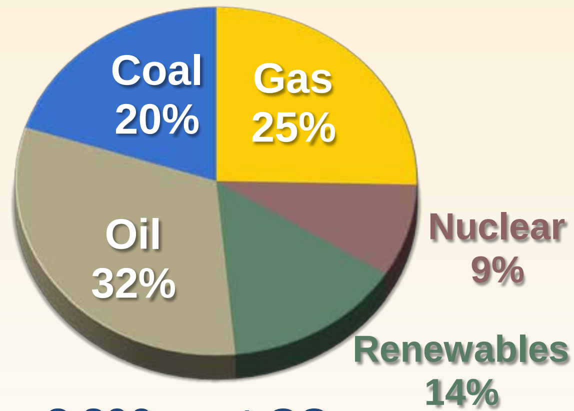
95 QBtu / Year
83% Fossil Energy



5,425 mmt CO_2

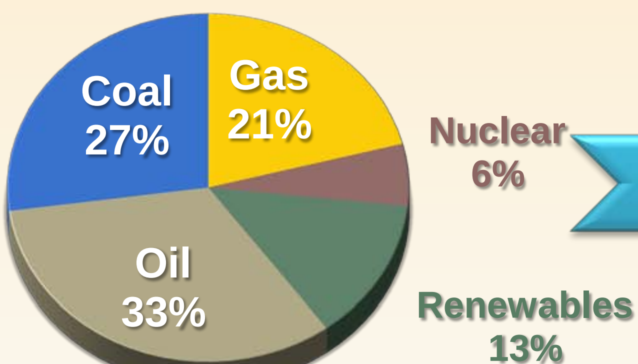
+ 14%
United States

108 QBtu / Year
77% Fossil Energy



8,806 mmt CO_2

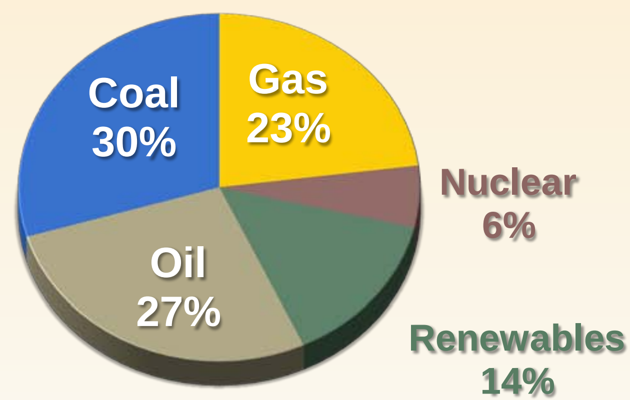
481 QBtu / Year
81% Fossil Energy



28,844 mmt CO_2

+ 51%
World

726 QBtu / Year
80% Fossil Energy



43,320 mmt CO_2

Sources: U.S. data from EIA, Annual Energy Outlook 2012er: World data from IEA, World Energy Outlook 2011

U.S. Coal Resources

Low rank: lignite and sub-bituminous coal

About 50% of the U.S. coal reserves

Nearly 50% of U.S. coal production

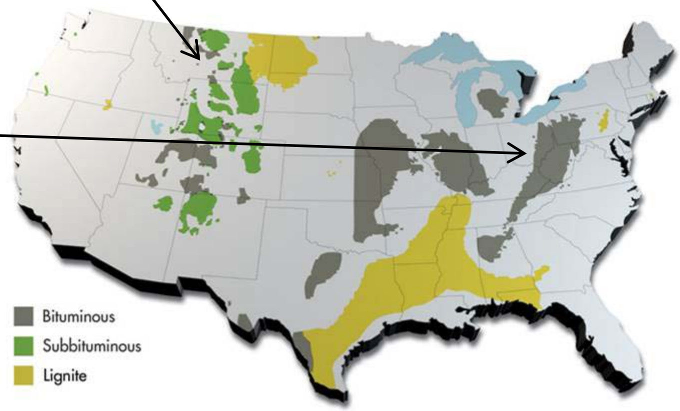
Lower sulfur

Bituminous coal

About 50% of the U.S. coal reserves

Higher heating value

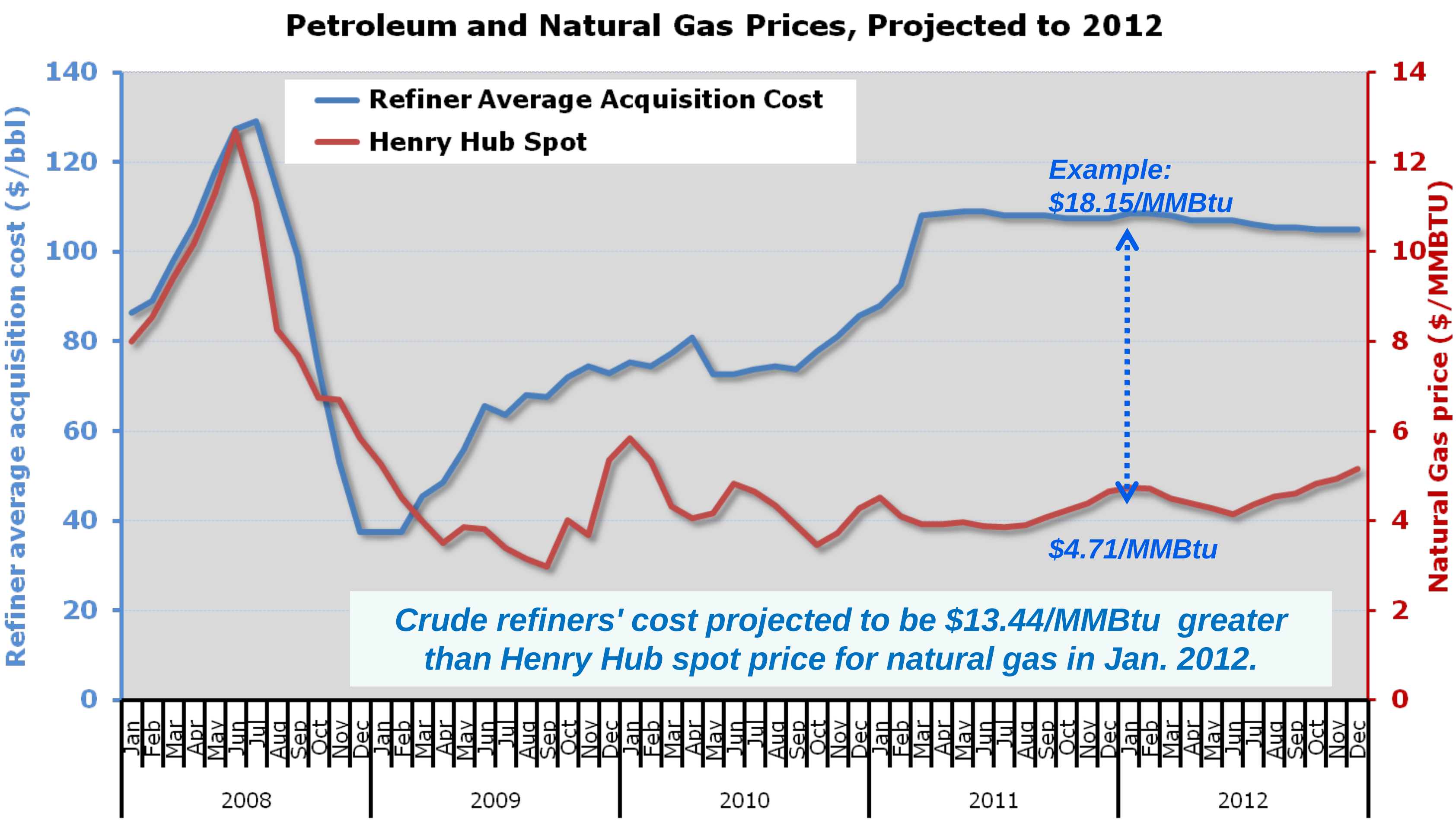
Lower moisture and mineral content



EIA forecasts significant growth in western coal production; declining eastern coal production

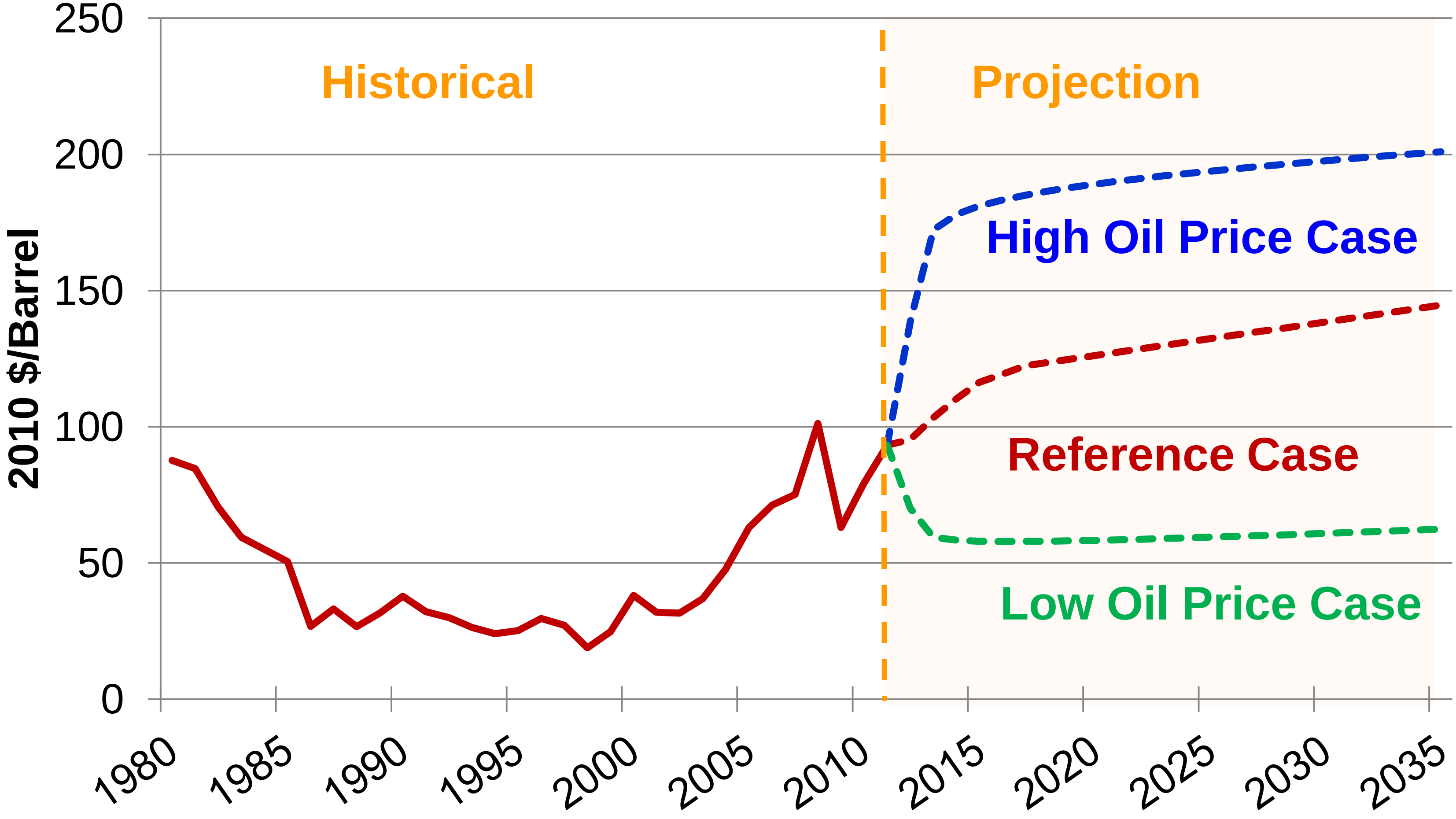
Low rank western coal cost per Btu will stay at about half that of eastern coal

Oil and Gas Price Comparison



Source: EIA's Short Term Energy Outlook, Table 2

Average World Oil Price Projections



Source: EIA AEO 2012 (early release), Figure 5

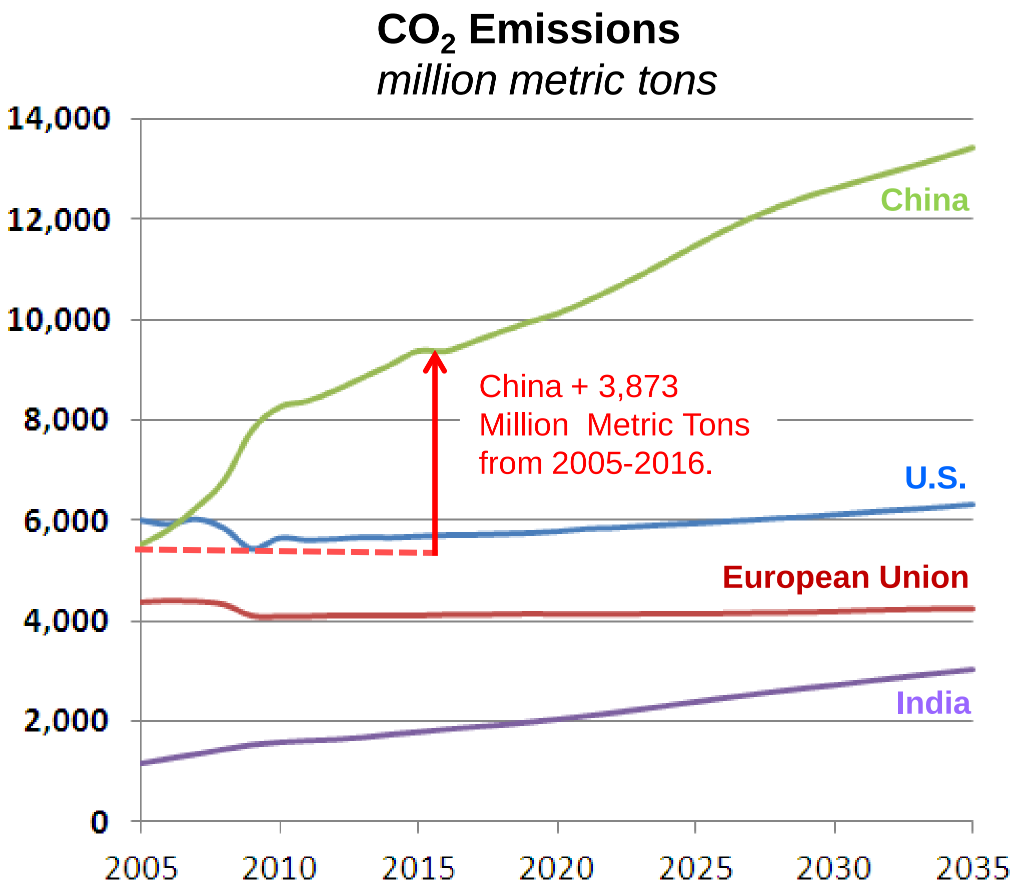
Carbon Capture is a Global Issue

The European Union are anticipated to maintain level of CO_2 release through 2035; 2020 for U.S.

China and India CO_2 emissions will substantially increase into 2035

By 2020, China's CO_2 emissions will eclipse U.S. and the European Union, combined

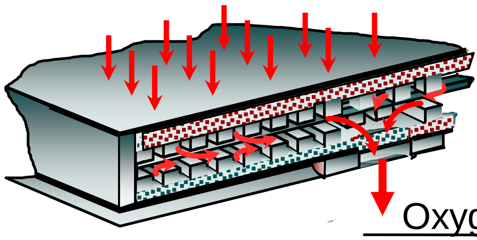
By 2015, China aims to cut CO_2 emissions per unit economic growth by 16 percent of 2011 levels



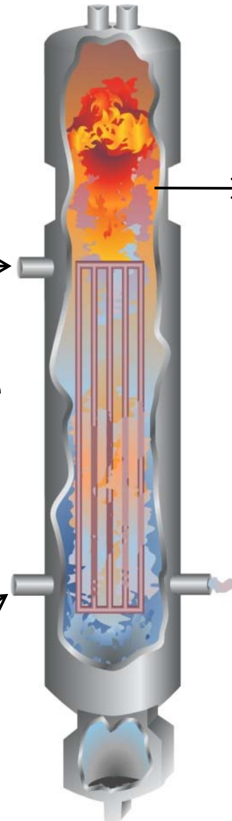
Source: *IEA World Energy Outlook 2010, Current Policies Scenario*

Active DOE Cooperative Agreements

Gasification Systems Program Projects



Oxygen



SYNGAS PROCESSING SYSTEMS

RTI Warm Gas Cleanup
ORD Pd Sorbent
APCI Sour PSA - scoping study
TDA Integrated CO_2 Removal & WGS* - scoping study
NCCC WGS Optimization
Eltron H_2/CO_2 Membrane

FEED SYSTEMS

APCI Ion Transport Membrane
PWR Dry Coal Feed Pump
GE Posimetric Pump*
– scoping study
EPRI CO_2-Coal Slurry*
– scoping study

Water Gas Shift

H_2 rich stream

CO_2

GASIFIER OPTIMIZATION AND PLANT SUPPORTING SYSTEMS

VPI Temperature Sensor	GTI Real-Time Flame Monitor Sensor
REI Syngas Cooler Fouling	GE Improve Availability and Reduce Costs
NCCC Transport Gasifier Optimization*	ORD Improve Refractory
ORD Low Rank Coal Optimization*	ORD Conversion and Fouling

*Low-rank Coal Alternative Feedstocks

ORD: NETL's Office of Research and Development

National Carbon Capture Center at the Power Systems Development Facility

Southern Company Services

Location: Wilsonville, AL

Subcontractors

American Electric Power

Arch Coal

Electric Power Research Institute

Luminant

NRG

Peabody Energy

Rio Tinto

Development and commercial scale-up of modular industrial scale gasification-based processes and components

National Carbon Capture Center

Southern Company Services

Goal

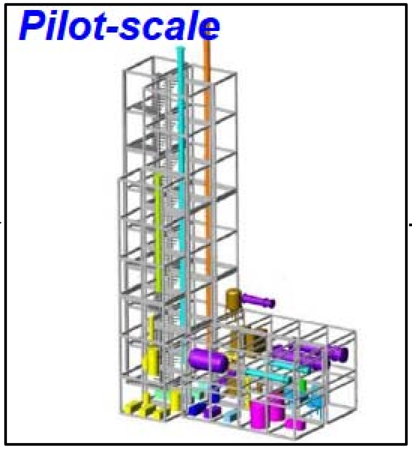
Accelerate path to cost-effective CO_2 capture technology for all 3 major areas of CO_2 Capture; post combustion, pre-combustion, oxy-combustion

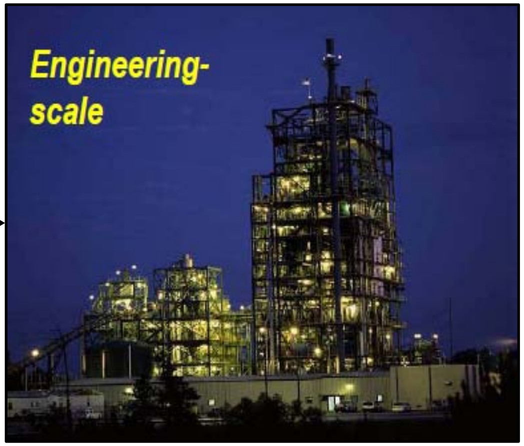
Technology

Flexible testing facilities from bench to engineering-scale

Project tasks

Modifications underway to enhance and enlarge pre-combustion CO_2 capture testing infrastructure to enable testing of membranes, sorbents and solvents





National Carbon Capture Center (NCCC)

Advanced Gasification and H_2 Separation

Fuel flexibility, filter materials, sensor development

1000 hour gasification test using PRB coal

- Evaluated new gasifier temperature control scheme
- Continued long-term evaluation of hot gas filter elements
- Conducted sensor development involving sapphire thermowell for gasifier service, coal-flow measurement device, and vibration type level detector
- 996 hour test of PRB sub-bituminous coal completed through Dec. 2011

Carbon capture

Modifications continue to enhance and enlarge pre-combustion CO_2 capture testing infrastructure to enable testing of membranes, sorbents, and solvents. Conducted evaluations of:

- Hydrogen and CO_2 membranes
- High-temperature palladium-based mercury sorbent
- CO_2 capture testing with new solvents
- Water-gas shift catalyst performance

Power Systems Development Facility (PSDF)

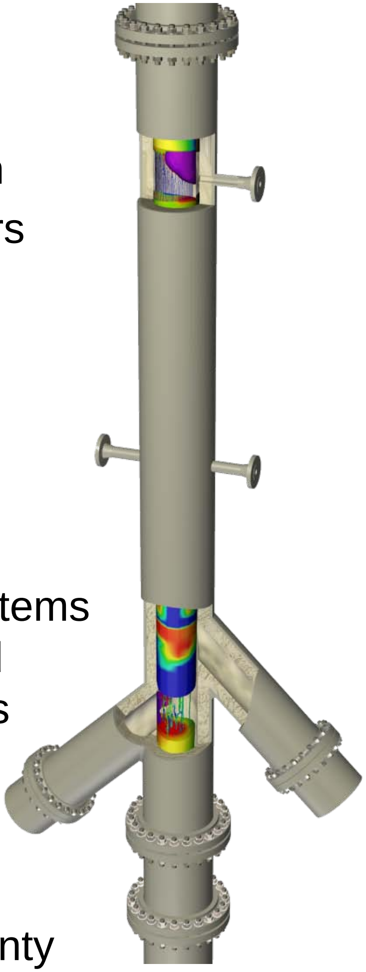
Project History - Accomplishments

History - Established by DOE in early '90s

- To accelerate development of more efficient advanced coal-based power plant technologies
- Research centered around high-temperature, high-pressure filtration
- Signed over 115 non-disclosure agreements (NDA)s with developers to support advancement of their technologies
- Air-blown Transport Gasifier commenced operation in 1999

Accomplishments - Results through 2011 include:

- 28 major gasification test campaigns
- 16,000 hours of gasification operation
- Successful engineering scale demonstration of advanced power systems technologies, including: hot gas particulate control device, advanced syngas cleanup systems, and high-pressure solids handling systems
- Developed gasifier suitable for low-rank fuels use
- Extensive successful operation on a variety of coals including: subbituminous,bituminous, and lignite
- TRIG^{TM} technology being used in CCPI demonstration, Kemper County



Ion Transport Membrane (ITM)

Air Products and Chemicals, Inc. (APCI)

Goal: Low cost oxygen production

Technology: O_2 separation from air utilizing peroskovite ceramic membrane technology

Project tasks (planned completion date 9/30/2015)

Conduct preliminary testing of 1 TPD modules in the ISTU to establish module performance

Design, build and test 100 TPD test system with at least thirty 1 TPD ITM modules (construction continuing)

(ARRA) Measure flux and purity performance of ceramic ITM modules designed for use in advanced energy systems and industrial systems with low carbon emissions

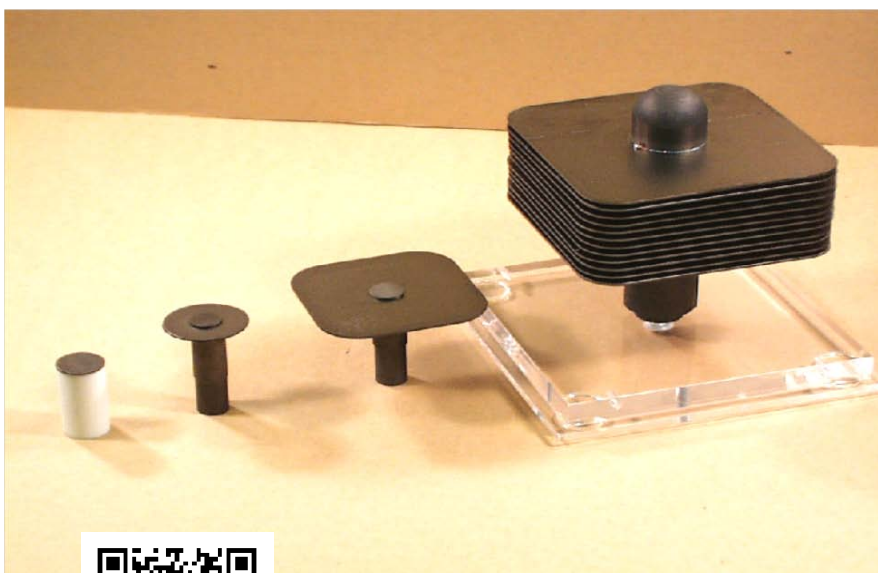
(ARRA) Develop project-quality cost estimations for a 2000 TPD Test Unit that will meet requirements for a test facility that addresses technical risk to enable a demonstration of the technology at large scale

Team Members: Ceramatec, Inc., The Pennsylvania State University, Concepts NREC, Williams International, LLC

Ion Transport Membrane (ITM)

Development of ITM Oxygen Technology

Progression to commercial size wafers



0.5 TPD Stack

1.0 TPD Stack

Ion Transport Membrane (ITM)

Air Products and Chemicals, Inc. (APCI)

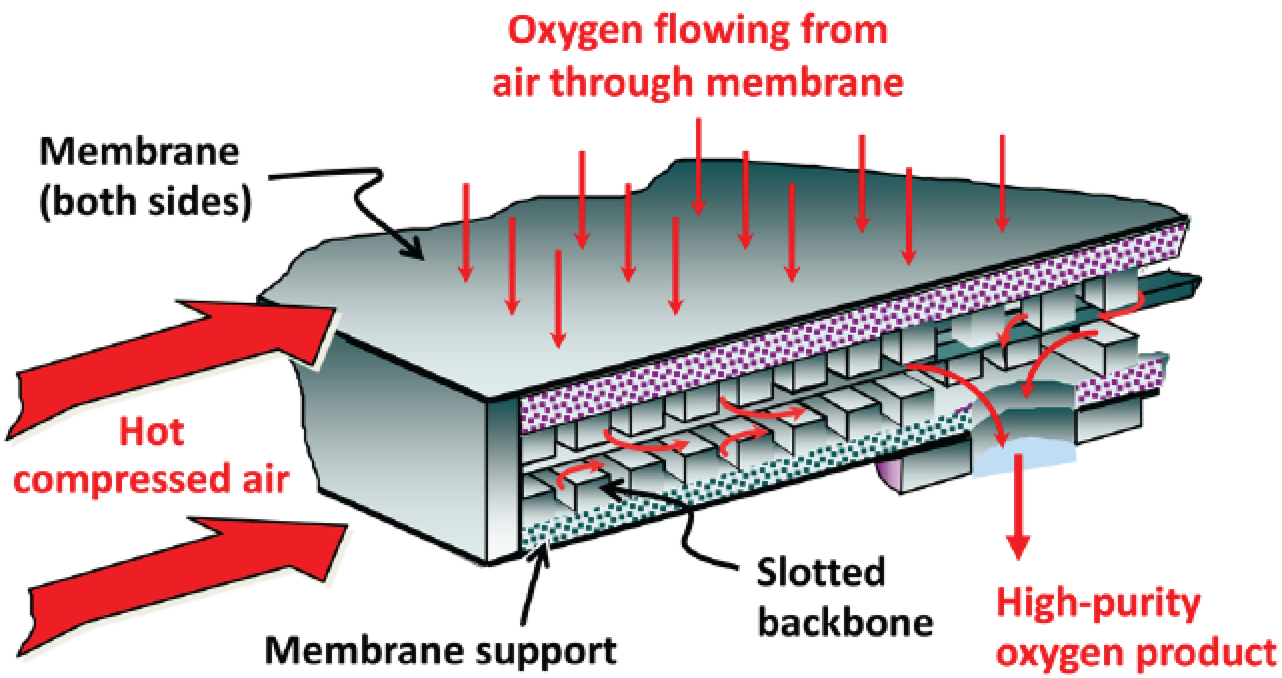
Ion Transport Membrane (ITM)

Supported thin-film, ceramic planar devices

Fast, solid state electrochemical transport of oxygen

Pressure-driven; compact

All the layers are composed of the same ceramic material



½-TPD module (multiple membranes)

Membrane Air Separation Advantages

Cryo-ASU vs. ITM in IGCC

IGCC Efficiency	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	0.8%	2.9%
With CCS	BASE	0.3%	2.2%

Improved Efficiency

Oxygen Plant Cost	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	-24.9%	-34.8%
With CCS	BASE	-24.5%	-36.3%

Better Economics

Levelized Cost of Electricity	Cryo-ASU	ITM with F-Class GT	ITM with G-Class GT
No CCS	BASE	-1.6%	-5.0%
With CCS	BASE	-2.1%	-4.9%

G-Class cases include full air-side integration of advanced gas turbine and oxygen plant

Source: Air Products and Chemicals, Inc.

High Pressure Solids Pump

Pratt & Whitney Rocketdyne

Goal: Reliable and consistent dry feed for high pressure IGCC leading to lower cost

Technology: Bulk solids form multiple stable “bridges” between parallel moving walls to feed dry solids across 1,000+ psi pressure gradient

Project tasks (Project decision point 3/31/2013, recipient has tasks planned through 9/30/2013)
Complete initial test series on nominal 600 tpd prototype pilot-scale dry solids pump and complete economic analysis

Team Members:
Pratt & Whitney Rocketdyne
Albany Research Center
University of North Dakota Energy & Environmental Research Center, Oak Ridge National Laboratory

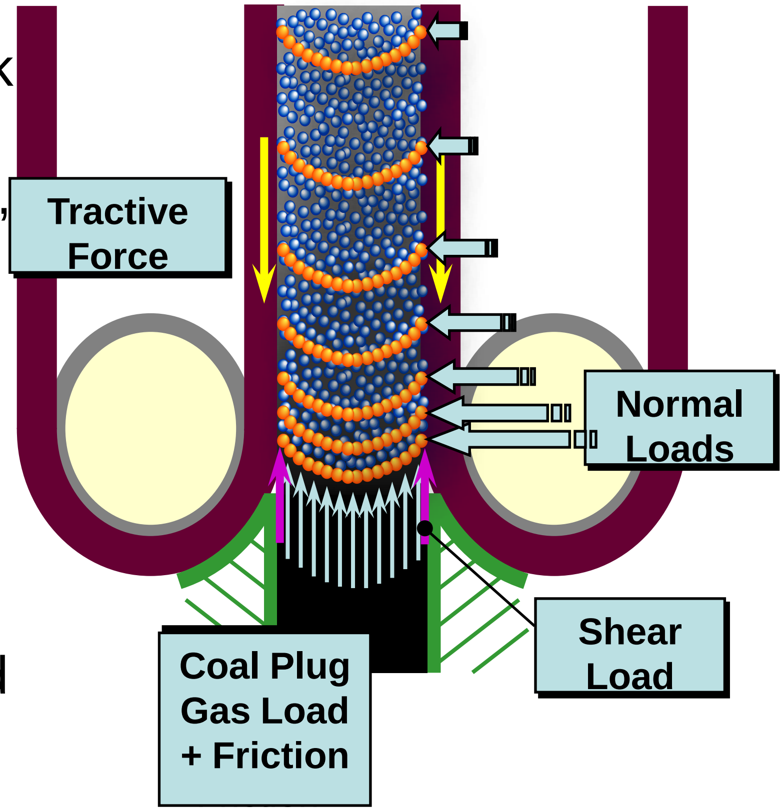
High Pressure Solids Pump

Pratt & Whitney Rocketdyne

Pump operation relies on ability of bulk solids to form multiple stable "bridges" or arch between parallel wall structure, bridges can support very large loads

Increasing load is transferred to sidewalls, making the bridge more stable, further increasing load will ultimately fail the sidewall

Extrusion or "pumping" occurs when sidewalls are moved mechanically and material is released by separating the walls



In "lock-up" there is no "slip" or relative motion between material and moving walls, device exhibits "positive displacement" with a volumetric displacement of unity

Benefits of Dry Feed System

General Electric Company

Goal: Evaluate and demonstrate the benefits of novel dry-feed technologies to effectively, reliably, and economically feed low-rank coal into commercial IGCC systems

Technology: The advanced technologies analyses will be based around the Posimetric® pump currently under development by GE

Project tasks (planned completion date 3/30/2013)

Complete report on test data supporting the potential value of the advanced technologies

Complete performance for Posimetric Feed System

Complete performance and economic calculations for baseline plant.

Team Members:

General Electric Company

CO_2 Slurry Feed

Electric Power Research Institute, Inc. (EPRI)

Goal: Reduce the cost and improve the efficiency of IGCC with carbon capture

Technology: High purity CO_2 stream as the carrier fluid to feed low rank coal into the gasifier

Project tasks (planned completion date 3/31/2013)

Complete plant-wide technical and economic analyses of low rank coals using both liquid CO_2 and water slurry feeds

Complete Technology Development Roadmap on the novel technology designed to reduce the cost of low rank coal gasification

Team Members:

Electric Power Research Institute
Dooher Institute of Physics and Energy
Worley Parsons Group, Inc.
Columbia University

Development of Prototype Commercial Gasifier Sensor

Gas Technology Institute

Goal: Develop and demonstrate a reliable, practical, and cost effective prototype sensor capable of monitoring gasifier interior temperature and other operational conditions in real time

Technology: Further development and demonstration of the Real Time Flame Monitoring of Gasifier Burner and Injectors sensor technology

Project tasks (planned completion date 7/31/2014)
Complete design of the purging system, complete sensor soft
Prepare and test sensor software package, confirm sensor accuracy is ±30º F
Design, build, and install sensor purging system

Team Members: Gas Technology Institute, Wabash River, ConocoPhillips Company, North Carolina State University

Single Point Sapphire Temperature Sensor

Virginia Polytechnic Institute

Goal: Develop an accurate temperature measurement system capable of withstanding harsh conditions for use in commercial full-scale gasification systems

Technology: A broadband polarimetric differential interferometric temperature sensor with a single-crystal sapphire to make an optically-based measurement

Project tasks (If no cost time extension approved by DOE, project will end on 12/31/2013)

Recipient plan includes two additional test campaigns to demonstrate viability of the sensor as well as the packaging

Team Members:
Virginia Polytechnic Institute
Eastman Chemical Company

Mitigation of Syngas Cooler Plugging & Fouling

Reaction Engineering International

Goal: Improve the availability of IGCC plants through improving the performance of the syngas cooler through reduced plugging and fouling

Technology: Combination of laboratory scale experiments to evaluate deposit strength and computational fluid dynamic modeling to evaluate designs to mitigate fouling and plugging

Project tasks (planned completion date 9/30/2014)

Perform deposit bond strength test using ash from gasifier
Complete computational fluid dynamic modeling of strategies to mitigate syngas cooler plugging and fouling for 5 scenarios

Team Members:
Reaction Engineering International, Salt Lake City
University of Utah, Salt Lake City

IGCC Affordability and Availability

General Electric Company

Goal: Reduce the time to technological maturity and enable IGCC plants to reach higher values of availability in a shorter period of time at a lower installed cost

Technology: Studies for identification and technical evaluation of concepts to reduce total installed cost and improve availability with broad applicability to the IGCCC industry including; integrated operations philosophy, modularization of gasification /IGCC plant, active fouling removal, improved slag handling

Project tasks (planned completion date 9/30/2014)
Develop a conceptual design for improved slag handling
Develop a conceptual design for an improved slip form structure
Prepare two preliminary designs

Team Members:
General Electric Company

Warm Gas Cleanup

Research Triangle Institute (RTI)

Goal: Higher efficiency, ultra clean syngas cleanup

Technology: Highly reactive sorbent in an integrated transport reactor system

Project tasks (planned completion date 9/30/2015)

Upload geological characterization data into NATCARB database

Complete design, construction and commissioning of the Warm Gas Cleanup demonstration (50 MWe) (construction continuing)

Achieve 5000 hours of cumulative planned operating time on pre-commercial scale high temperature desulfurization unit

Team Members: Research Triangle Institute, Tampa Electric Company, Eastman Chemical Company , BASF Corporation , The Shaw Group Inc. , Sud Chemie Inc. , AMEC, TECHNIP USA

Warm Gas Cleanup – RTI

Previous Testing at Eastman Chemical

RTI Warm Gas Cleanup Technologies

Cleans multi-contaminants from coal-derived syngas while creating pure sulfur product

High Temperature Desulfurization Process

> 99.9 % removal of both H_2S and COS (to < 5 ppmv levels)

> 3,000 hours of operation at 0.3 MWe

Direct Sulfur Recovery Process

> 99.8 % SO_2 conversion to elemental sulfur

96 % ammonia removal

90 % mercury and arsenic removal

High Temperature Desulfurization Process

Direct Sulfur Recovery Process

Multi-contaminant Control Test System

Pilot Plant Operation at Eastman's Gasification Facility, Kingsport, TN

Advanced CO_2 Capture Technology for Low Rank Coal IGCC Systems

TDA Research, Inc

Goal: Demonstrate technical and economic potential for an integrated CO_2 scrubber/ water gas shift catalyst

Technology: Highly reactive sorbent in an integrated transport reactor system

Project tasks (planned completion date 9/30/2013)

Test sorbents/catalysts to determine working capacity and plant efficiency

Complete testing with protoype unit

Complete techno-economic analysis

Team Members:

TDA Research, Inc.
University of California at Irvine
Southern Company
ConocoPhillips

Hydrogen Transport Membrane (HTM)

Eltron Research, Inc.

Goal: Lower cost H_2 separation and CO_2 capture for IGCC

Technology: Dense metal membrane to separate H_2 from shifted syngas, leaving CO_2 at high pressure

Project tasks (planned completion date 9/30/2015)

Complete testing of lab- and bench-scale units at Eltron (ongoing)

Complete testing of 5-12 lb/day H_2 production unit using real coal-derived synthesis gas (ongoing)

Design, construct, and evaluate performance of pilot-scale unit

Team Members:

URS

Hydrogen Transport Membrane (HTM)

Eltron Research, Inc.

Hydrogen Transport Membrane

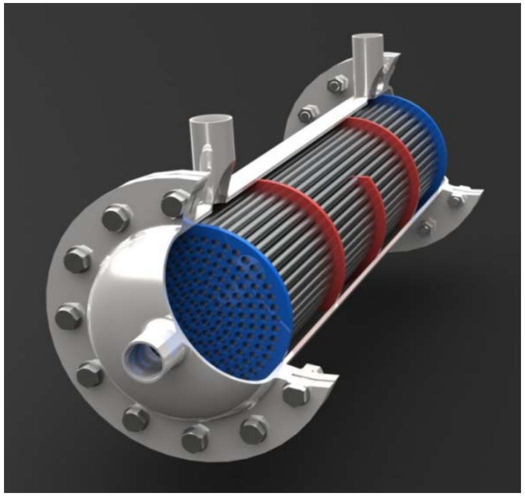
High CO_2 retentate pressure

Allows capture of high pressure CO_2

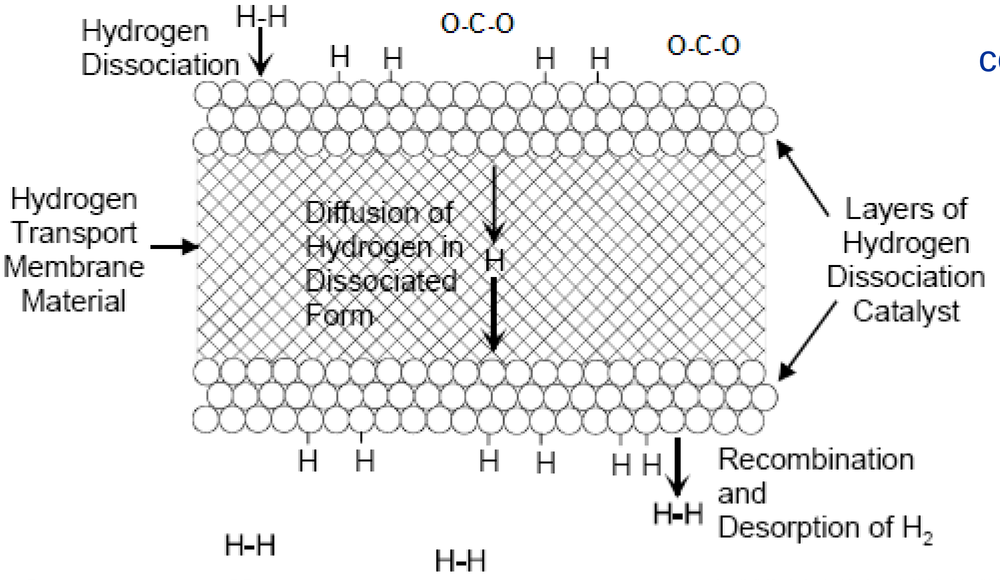
High hydrogen recoveries >90%

Essentially 100% pure hydrogen

Low cost, long membrane life



Conceptual design of commercial membrane unit



Eltron Research & Development Tech Brief http://www.eltronresearch.com/docs/Hydrogen_Membrane_Technology_Summary.pdf

Reliability, Availability & Maintainability R&D

Recently Awarded Projects

Mitigation of Syngas Cooler Plugging and Fouling (Reaction Engineering International)

Experimental Testing: Deposit bond strength and characterization

Modeling: Investigate deposit behavior in the syngas cooler section, evaluate process conditions and equipment designs for mitigation of syngas cooler plugging and fouling

Field Test: Validate specific means to implement mitigation methods

Feasibility Studies to Improve Plant Availability and Reduce Total Installed Cost in IGCC Plants (GE)

Work on tasks, with broad applicability to the IGCC industry

Integrated operations philosophy

Modularization of gasification/IGCC plant

Active fouling removal

Improved slag handling

NETL Office of Research & Development

Gasification Projects

Refractory Improvement

Develop improved performance refractory liners

Model gasifier slag

Manage slag viscosity and refractory wear, evaluate additives

Conversion and Fouling

In slagging gasifiers using coal, petcoke or blends

- Improve the carbon conversion efficiency to syngas
- Reduce convective syngas cooler fouling

Low-Rank Coal Optimization

Pretreatment and kinetic co-feed experimental efforts

Demonstrate the models the NCCC/TRIG under co-feed conditions

Warm Syngas Cleanup

Conduct both lab and pilot-scale R&D for cost efficient sorbents for trace contaminant capture

Advanced Virtual Energy Simulation Training And Research (AVESTARTM) Center

Establish the world-class center for addressing key operational and control challenges arising in IGCC plants with carbon capture

NETL In-House R&D (ORD-RUA)

NETL Office of Research & Development
Gasification Projects

Refractory Improvement

Develop improved performance refractory liners that are carbon feedstock flexible (coal, western coal, petcoke)

Model gasifier slag for refractory interactions, downstream phases and material interactions (syngas coolers)

Manage slag viscosity and refractory wear, evaluate additives

Conversion and Fouling

In slagging gasifiers using coal, petcoke or mixtures of them to:

- Improve the carbon conversion efficiency to syngas
- Reduce convective syngas cooler fouling

Collaborate with industry to ensure proper technology development and transfer

NETL Office of Research & Development

Gasification Projects

Low-Rank Coal Optimization

Pretreatment and kinetic co-feed experimental efforts to support and validate the development of a hierarchy of device scale gasifier models with uncertainty quantification

Demonstrate the models with UQ for the NCCC/TRIG under co-feed conditions and optimize co-feed performance

Warm Syngas Cleanup

Conduct both lab and pilot-scale R&D for cost efficient sorbents for trace contaminant capture of high efficiency coal gasification plant

Advanced Virtual Energy Simulation Training and Research (AVESTAR™) Center

Training Center: 3D virtual simulation of IGCC plant

Establish the world-class center for addressing key operational and control challenges arising in IGCC plants with carbon capture

Refractory Improvement

NETL Office of Research and Development

Refractory Development for Mixed Feedstock Use

Determine mechanisms of wear in NETL refractory materials under development.

Determine refractory corrosion mechanisms in current generation commercial refractory liner materials exposed to coal slag, important for understanding how to overcome limitations in current refractory liner materials

Slag Management (Current Emphasis)

Determine critical information needed for slag management in gasifiers, which will be tracked in commercial gasifiers and predicted in models to increase gasifier RAM

Advanced Refractory For Gasifiers

Rotary Slag Test

New refractory chemistry

Increases mechanical durability

Reduces slag penetration

Conventional refractory after rotary slag testing

Phosphate modified high-chrome oxide refractory material

Advanced Refractories for Gasifiers

NETL Office of Research and Development

Current refractory goal is to refine/evaluate composition in commercial gasifiers

Cr^{+6} formation in high Cr_2O_3 refractories is thermodynamically predicted not to be an issue with current carbon feedstock

Low oxygen partial pressure results in low Cr^{+6} formation

Gasification environment has O_2 partial pressure about 10^{-8}

Conversion and Fouling

NETL Office of Research and Development

Modeling

Evaluate and validate sub-models for particle-slag interaction, particle fragmentation, and mineral matter chemistry (sulfur release) and implement into CFD model

Develop and evaluate reduced order model to predict mineral matter split between slag and fly ash for entrained-flow gasifier

Convective Syngas Cooler Fouling

Literature survey of deposition models

Investigate gasifier ash deposits to determine problematic ash characteristics

Kinetics

Effect of pressure on pyrolysis kinetics

Preliminary gasification kinetics at high pressure

Slag Characterization

Continue to characterize coal and petcoke blends, characterize ash and slag, begin studies of FeS and VOx behavior in slag

Control of Ash in IGCC

Regional University Alliance

Goal: Solutions to IGCC Ash Management Problems

Unconverted carbon in gasification flyash

Syngas cooler fouling

Development of Models and Techniques to improve plant operations

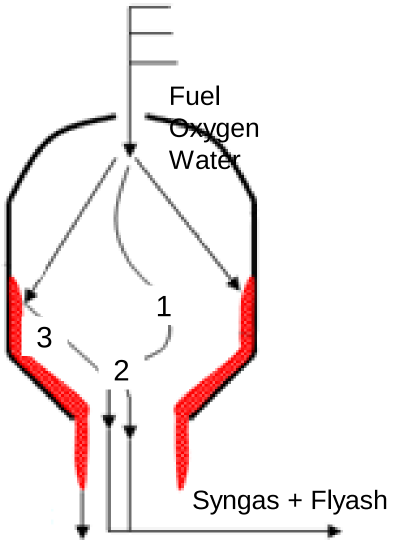
Adaption of “Particle Population Model” used for predicting CFB ash splits

Inorganic transformations and char/slag interactions

Particle trajectories and deposition modeling

Gasification kinetics

Coordinate and leverage R&D at NETL and three universities (PSU, CMU and WVU)



1. Particles contact and coalesce with slag
2. Particles do not contact slag
3. Particles contact but do not coalesce with slag

Low Rank Coal Optimization

NETL Office of Research and Development

Kinetics:

Development of NETL's Carbonaceous Chemistry for Computational Modeling (C3M) software to bridge coal kinetics software (PCCL, CPD, etc) and available kinetic experiments with CFD software (MFIX, Fluent, Barracuda), other models

Provide modelers and experimentalist with a virtual kinetic laboratory

Fuel Pretreatment

Expand and further test the grinding laws developed in FY11
Correlate the NETL lab scale results with large scale grinding energies

Multiphase Models

NETL's open source suite of multiphase solvers such as MFIX-DEM, MFIX continuum, MFIX-PIC and multiphase Reduced Order Models will be used to aid in the design and optimization of operating conditions and establishing performance trends in the NCCC/TRIG with uncertainty quantification

Warm Syngas Cleanup

NETL Office of Research and Development

Elevated temperatures results in higher IGCC thermal efficiency

Palladium-based sorbents are currently among the most promising candidates for high-temperature capture of mercury, arsenic, selenium, phosphorus and the other trace elements

Progress:

2007 - License agreement between the NETL and sorbent manufacturer Johnson Matthey

2008 - The technology received the R&D 100 award

2009 to present - Over 99% removal of mercury, arsenic, and selenium from dirty syngas slipstreams at 550°F over several weeks testing at the National Carbon Capture Center

Present - Identifying an optimum form of the palladium sorbent (loading, support, alloy)

Advanced Virtual Energy Simulation Training And Research (AVESTAR™) Center

NETL Office of Research and Development

Features

R&D, Training, and Education for the Operation and Control of Advanced Energy Systems with CO_2 Capture and Storage

Real-time Dynamic Simulators with Operator Training System (OTS) Capabilities

3D Virtual Immersive Training Systems (ITS)

Benefits

OTS for normal and faulted operations, plant start-up, shutdown, and load following/shedding

ITS for added dimension of plant realism

OTS/ITS for training both control room and plant field operators, promoting teamwork

Work force development in IGCC plant and CO_2 capture operations

Advanced R&D in process dynamics, model predictive control, sensors, RT optimization, 3D virtual plants, and more

AVESTAR™

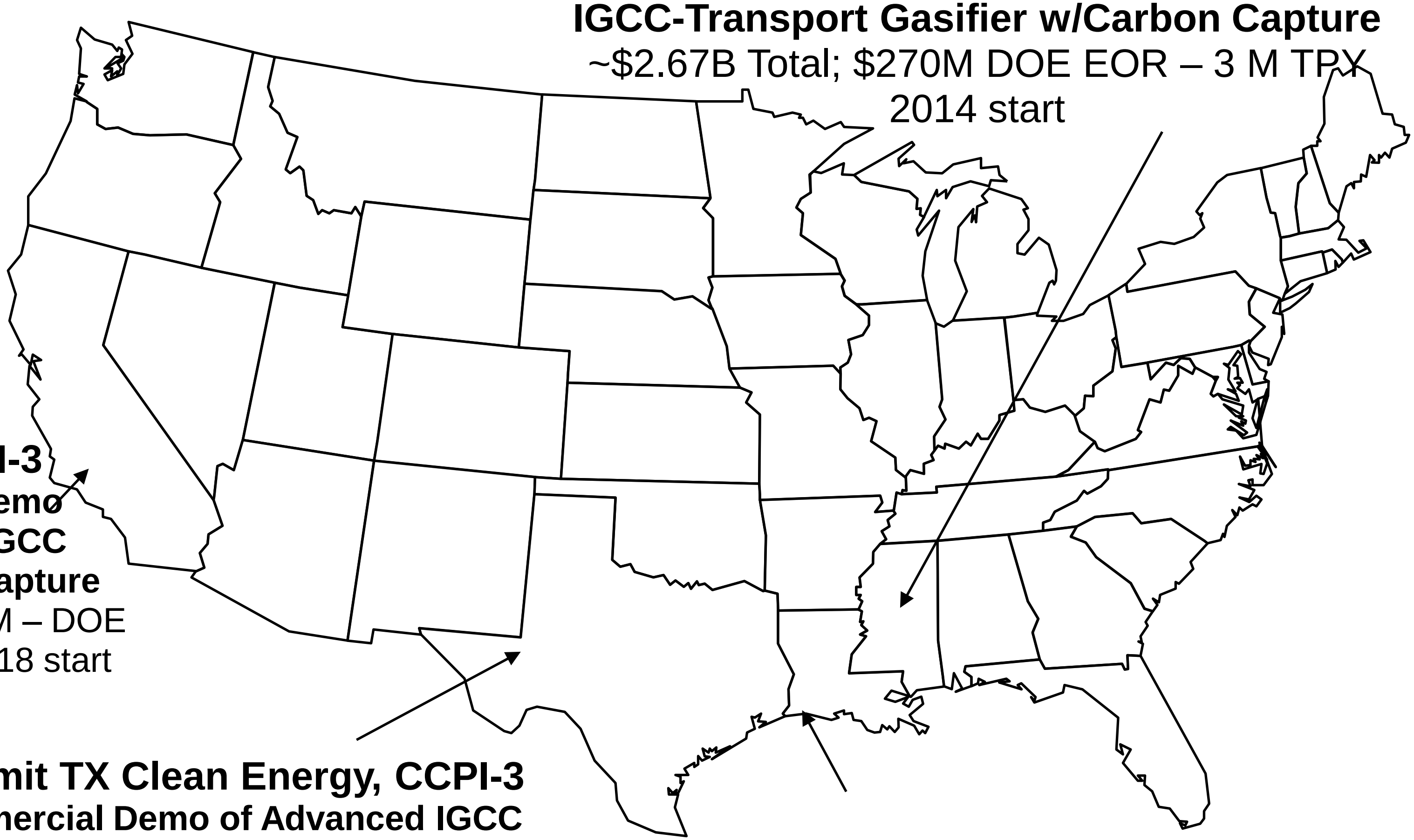
For more information on AVESTAR and IGCC training courses, please send email to AVESTAR@netl.doe.gov

DOE Supported Gasification Demonstration Projects

DOE Supported IGCC Demonstration Projects

Clean Coal Power Initiative, Industrial Capture & Storage

Southern Company, CCPI-2 Kemper County
IGCC-Transport Gasifier w/Carbon Capture
~$2.67B Total; $270M DOE EOR – 3 M TPY
2014 start



HECA, CCPI-3
Commercial Demo
of Advanced IGCC
w/ Full Carbon Capture
~$4B – Total, $408M – DOE
EOR – 3M TPY 2018 start

Summit TX Clean Energy, CCPI-3
Commercial Demo of Advanced IGCC
w/ Full Carbon Capture
~$1.7B – Total, $450M – DOE
EOR – 3M TPY 2018 start

Summary of Gasification Demonstration Projects and Products

Recipient Project	Products	CO_2 Capture Technology	CO_2 EOR Sequestration (TPY)	Seq. Start
SCS Kemper	582 MWe net ~135,000 TPY- Sulfuric acid ~20,000 TPY- Ammonia	Selexol®	3,000,000	2014
Summit TCEP	400 MWe gross Granulated Urea ~2,126 tons/day Sulfuric acid ~58 tons/day	Rectisol®	3,000,000	2014
HECA	Up to 300 MW (power mode) Nominal 165 MW (ammonia mode) Solid Urea 1700 tons/day Urea Ammonium Nitrate Solution 1400 tons/day.	Rectisol®	2,500,000	2019

Southern Company Services, Inc. CCPI-2

Advanced IGCC with CO_2 Capture

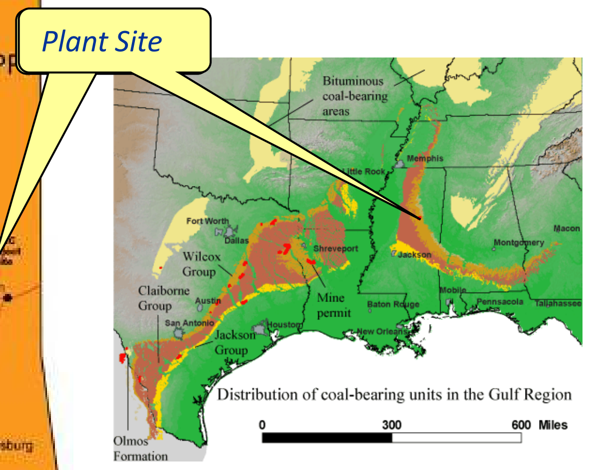
Kemper County, MS
582 MWe (net) IGCC
2 KBR Transport gasifiers,
2 Siemens combustion turbines
1 Toshiba steam turbine

Mississippi Lignite Fuel

65% CO_2 capture (Selexol® process)
3,000,000 tons CO_2/year

EOR Sequestration site TBD (Start 2014)

DOE Share: $270 Million



Key Dates

- **Project Awarded: Jan 2006**
- **Project moved to MS: Dec 2008**
- **Construction: Jul 2010**
- **NEPA ROD: Aug 2010**
- **Operations: May 2014**

Status

- **NEPA Record of Decision: 8/19/2010**
- **Construction initiated: 9/16/2010**
- **Process equipment installation underway**

Hydrogen Energy California
Advanced IGCC-Polygen

Kern County, CA
Up to 235 MWe (net) IGCC
New Mexico subbituminous coal and petcoke
1 million tons/yr Urea/UAN
90% CO_2 capture
2,500,000 tons CO_2/year
EOR - Elk Hills oil field (start: TBD)
Maximize use of non-potable water for power production
Recycle all IGCC/project waste water,100% zero liquid discharge
DOE - $408 Million

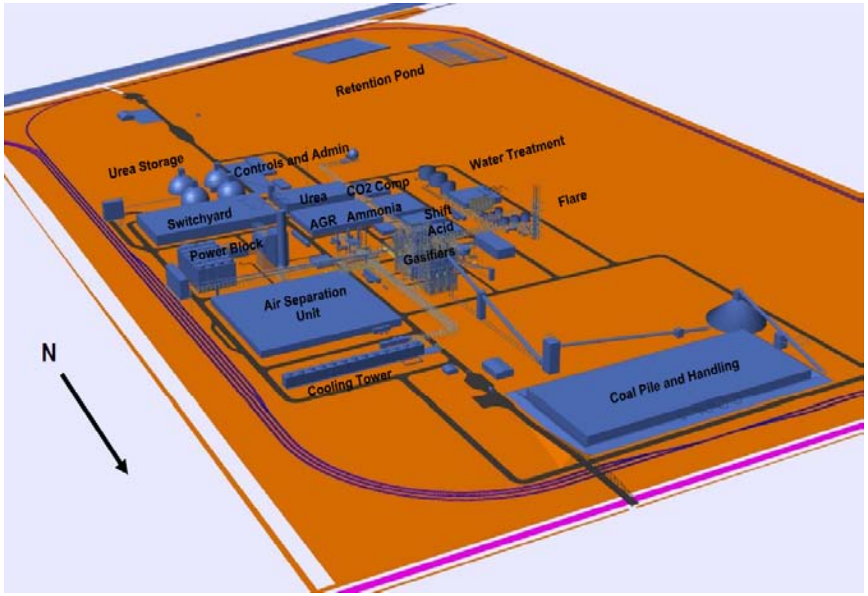
Key Dates
- **Project Awarded: 9/30/2009**
- **Project Being Re-baselined**

Status
- **New Owner, SCS Energy: 9/2011**
- **FEED initiated: 9/21/2011**
- **Sulfur recovery unit process design: 9/27/2011**
- **NEPA public scoping meeting scheduled: 7/12/2012**

Summit Texas Clean Energy, LLC CCPI-3

Advanced IGCC-Polygen

Penwell, Ector County, TX
400 MWe (gross)IGCC
Siemens gasification & power block
SFG-500 gasifiers (2 x 50%)
High H_2 SGCC6-5000F
combined cycle (1 x 1)
PRB sub bituminous coal
90% CO_2 capture
3,000,000 tons CO_2/yr
2-stage Water Gas Shift
Linde Rectisol ® AGR
Permian Basin EOR (Start: 2014)
DOE Share: $450 Million



Key Dates

- **Project Awarded: Jan 2010**
- **Construction: Jun 2012**
- **Financial Close: 1st Q FY2012**
- **Operation: Jul 2014**

Status

- **Air permit: Dec 2010**
- **Urea contract: Jan 2011**
- **CO_2 contract (60% of total): May 2011**
- **Record of Decision: Sep 2011**
- **Power off-take agreement executed: Dec 2011**

Leucadia Energy, LLC ICCS Area 1
Petcoke Gasification to Methanol

Lake Charles, LA

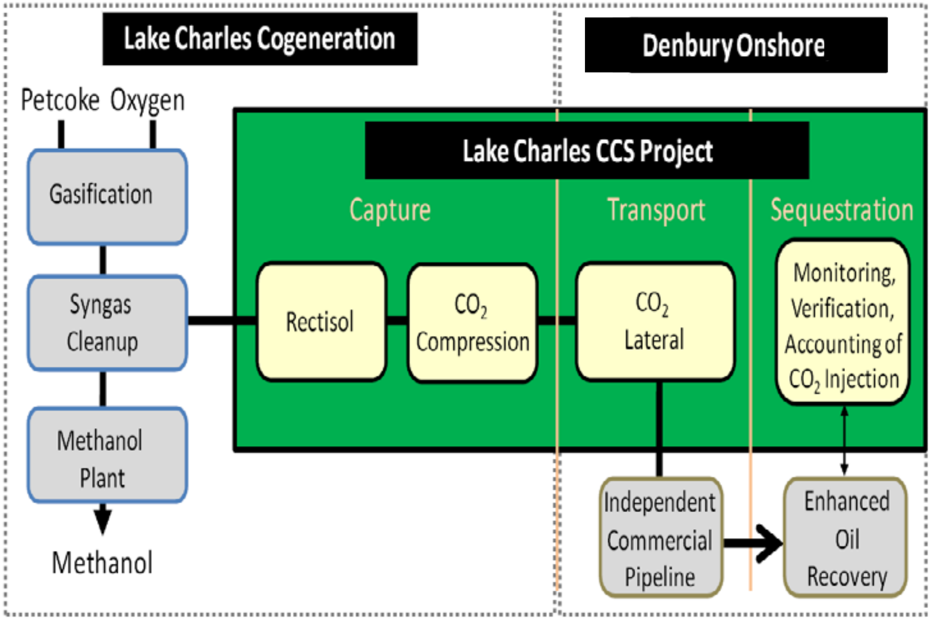
GE Energy Gasification
(4 gasifiers: 3 hot/1 spare)

730 Million gallons/year methanol

90% CO_2 capture (Rectisol® process); 4,000,000 tons CO_2/year

CO_2 to Denbury pipeline for EOR in Texas at the West Hastings oil field (Start 2015)

Total Project: $436 Million
DOE Share: $261 Million (60%)



Key Dates
- Phase 2 Awarded: Jun 17, 2010
- Complete FEED: Jul 2011
- Construction: Oct 2012
- Operation: Jun 2015

Status
- FEED completed
- NEPA EIS in progress
- Negotiating product off-take agreements

Mesaba Energy Project CCPI-2

Advanced IGCC

Taconite, Minnesota

No Sequestration

606 MWe(net)

ConocoPhillips E-Gas™ technology

- 2 operating gasifiers + 1 spare

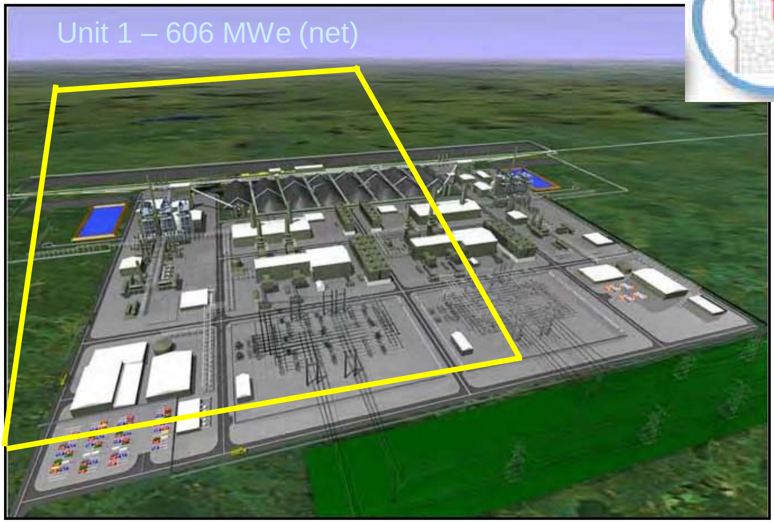
2 GE 7FB turbines and 1 steam

Bituminous and/or blend of sub-bituminous and pet-coke

Status:

- Notice of Availability (NOA) for the Final EIS Issued Nov. 2009
- Completing pre-construction permitting

EXCELSIOR ENERGY



Permits Approved

- Large Electric Power Generating Plant Site
- High Voltage Transmission Line
- Route Permit Pipeline Route

Systems Analysis

Gasification Systems Program

NETL's Program Analysis Support

On-going and Planned Gasification Studies

Low Rank Coal:

Parallel screening studies for Gasification FY11 awards

Cost and Performance Baseline for TRIG™

- PRB and ND Lignite Air Blown IGCC
- Texas Lignite Air and Oxygen Blown IGCC
    - Co-feeding of biomass to meet 90% equivalent CCS

IGCC with CCS Pathway Study: Low Rank Coal

Co-production assessments

Altitude versus shipping sensitivity analysis

IGCC availability studies:

Identifying gaps for conventional technologies

Setting targets for advanced technologies

General advanced technology assessments:

IGCC with CCS Pathway: Bituminous Coal, Updates

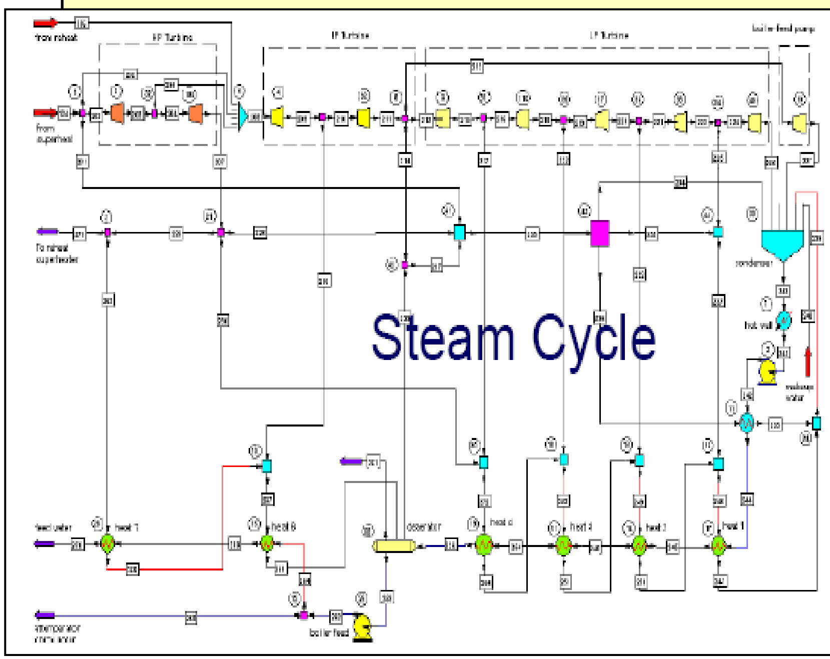
- DOE IGCC portfolio + PWR compact gasifier assessment
- Pressure sensitivity analysis

Updated WGCU assessment - learnings from TECO design

Technical Approach

1. Extensive Process Simulation (ASPEN)

- All major chemical processes and equipment are simulated
- Detailed mass and energy balances
- Performance calculations (auxiliary power, gross/net power output)



2. Cost Estimation

- **Inputs from process simulation** (Flow Rates/Gas Composition/Pressure/Temp.)
- **Sources for cost estimation**
  - WorleyParsons
  - Vendor sources where available
- **Follow DOE Analysis Guidelines**

Systems Analysis

Bituminous Baseline Study

Full presentation available at:

http://www.netl.doe.gov/energy-analyses/baseline_studies.html

Study Matrix

Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/ Boiler	Acid Gas Removal/ CO_2 Separation / Sulfur Recovery	CO_2 Cap
IGCC	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)	F Class	GEE	Selexol / - / Claus	
				Selexol / Selexol / Claus	90%
			CoP E-Gas	MDEA / - / Claus	
				Selexol / Selexol / Claus	90%
			Shell	Sulfinol-M / - / Claus	
				Selexol / Selexol / Claus	90%
PC	2400/1050/1050		Subcritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
	3500/1100/1100		Supercritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
NGCC	2400/1050/1050	F Class	HRSG		
				- / Econamine / -	90%

GEE – GE Energy
CoP – Conoco Phillips

IGCC Performance Results

	GE Energy		E-Gas		Shell	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Gross Power (MW)	**748**	**734**	**738**	**704**	**737**	**673**
Auxiliary Power (MW)						
Base Plant Load	25	26	24	28	22	25
Air Separation Unit	98	115	86	111	85	103
Gas Cleanup/CO_2 Capture	3	19	3	20	1	19
CO_2 Compression	-	31	-	31	-	30
Total Aux. Power (MW)	126	191	113	190	108	177
Net Power (MW)	622	543	625	514	629	497
Heat Rate (Btu/kWh)	8,756	10,458	8,585	10,998	8,099	10,924
Efficiency (HHV)	**39.0**	**32.6**	**39.7**	**31.0**	**42.1**	**31.2**
Energy Penalty[1]	**-**	**6.4**	**-**	**8.7**	**-**	**10.9**

[1] CO_2 Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO_2 Capture

PC and NGCC Performance Results

	Subcritical		Supercritical		NGCC	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Gross Power (MW)	**583**	**673**	**580**	**663**	**565**	**511**
Base Plant Load	28	45	25	41	10	12
Gas Cleanup/CO_2 Capture	5	29	5	27	0	10
CO_2 Compression	-	49	-	45	-	15
Total Aux. Power (MW)	**33**	**123**	**30**	**113**	**10**	**37**
Net Power (MW)	550	550	550	550	555	474
Heat Rate (Btu/kWh)	9,277	13,046	8,687	12,002	6,798	7,968
Efficiency (HHV)	**36.8**	**26.2**	**39.3**	**28.4**	**50.2**	**42.8**
Energy Penalty[1]	**-**	**10.6**	**-**	**10.9**	**-**	**7.4**

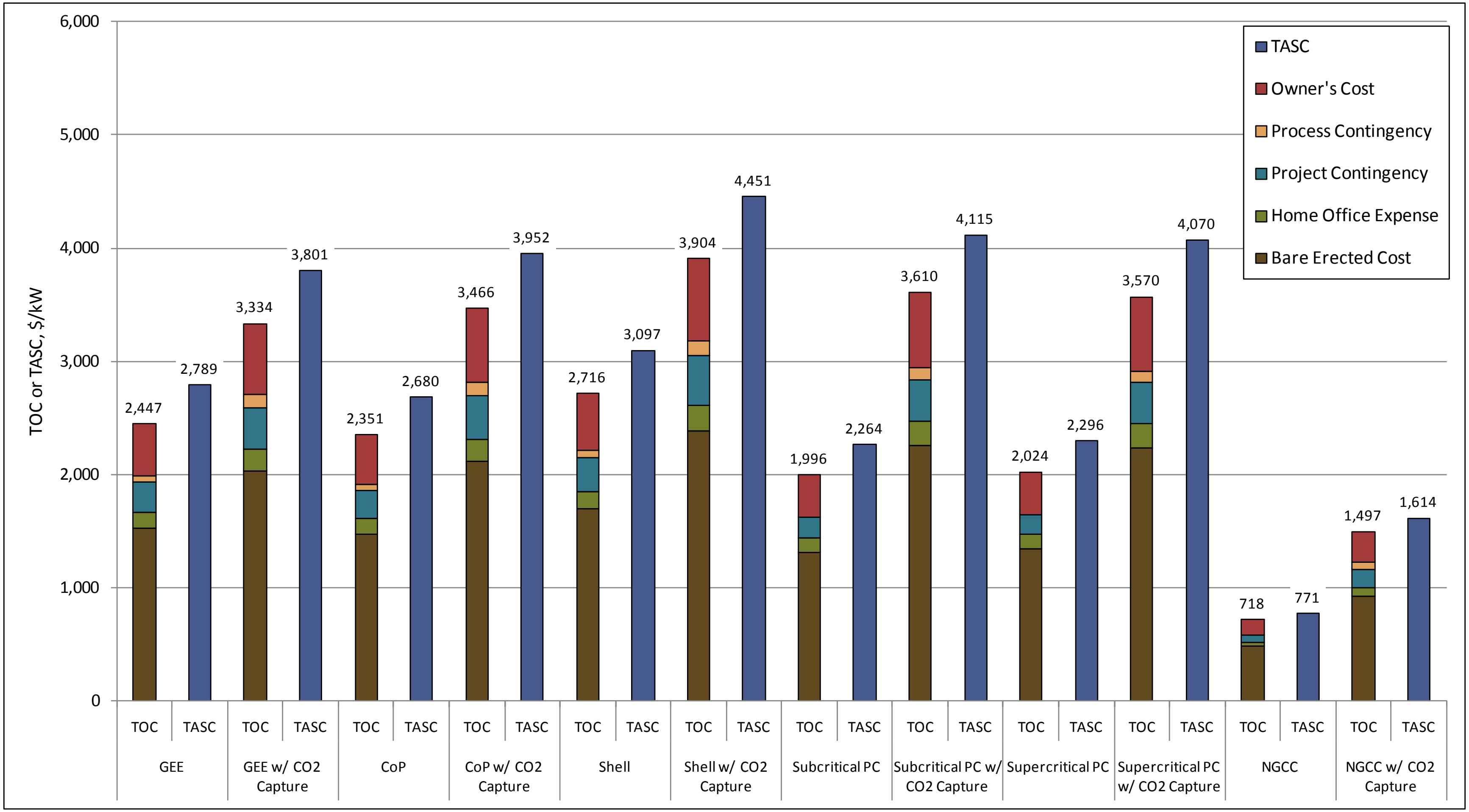
[1]CO_2 Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO_2 Capture

IGCC Economic Results

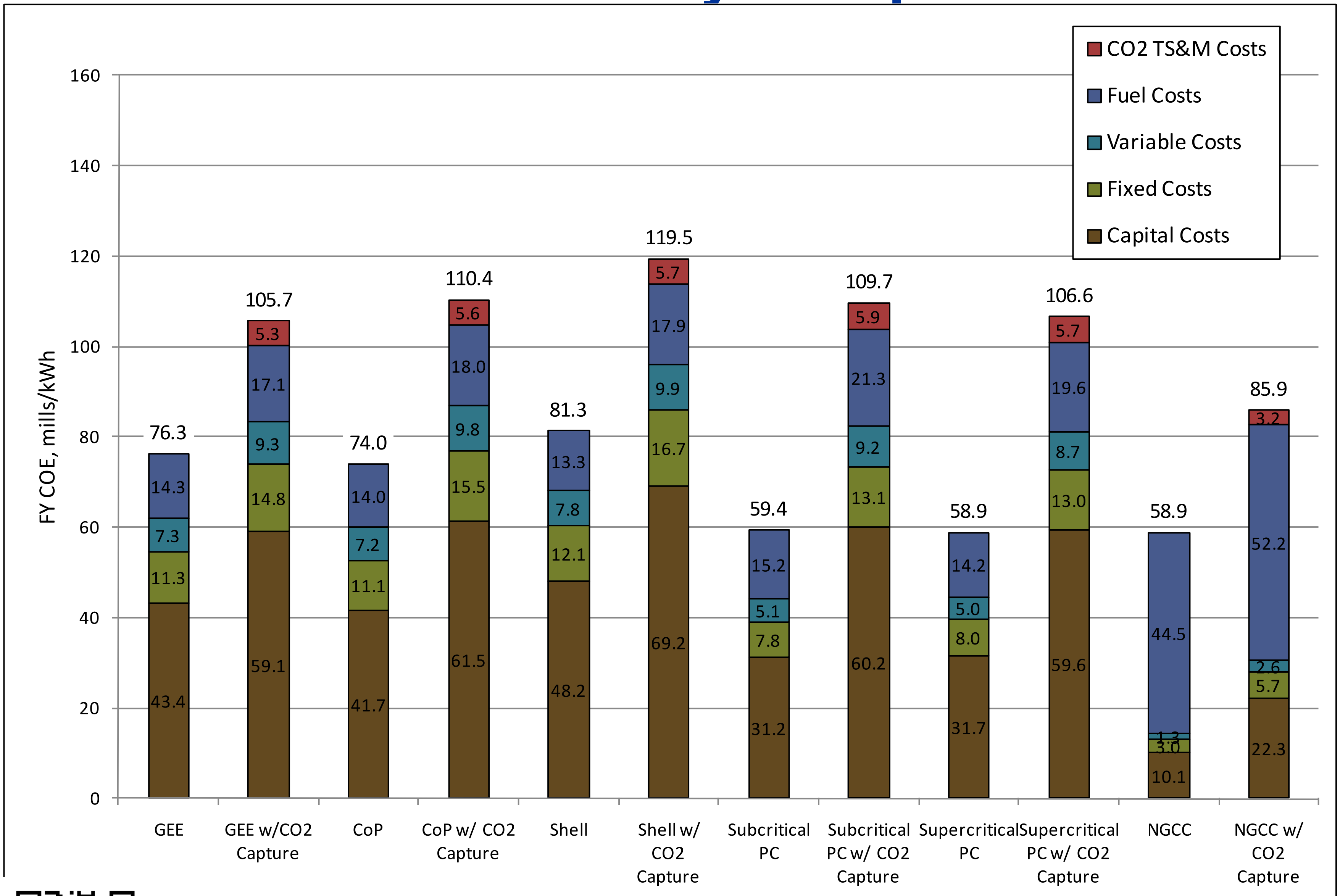
	GE Energy		E-Gas		Shell	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Plant Cost ($/kWe)[1]						
Base Plant	1,426	1,708	1,423	1,804	1,719	2,164
Air Separation Unit	312	429	281	437	285	421
Gas Cleanup/CO_2 Capture	249	503	209	500	213	521
CO_2 Compression	-	71	-	76	-	75
Total Plant Cost ($/kWe)	**1,987**	**2,711**	**1,913**	**2,817**	**2,217**	**3,181**
Capital COE ($/MWh)	43.4	59.1	41.7	61.5	48.2	69.2
Fixed COE ($/MWh)	11.3	14.8	11.1	15.5	12.1	16.7
Variable COE ($/MWh)	7.3	9.3	7.2	9.8	7.8	9.9
Fuel COE ($/MWh)	14.3	17.1	14.0	18.0	13.3	17.9
CO_2 TS&M COE ($/MWh)	0.0	5.2	0.0	5.5	0.0	5.6
Total COE[2] ($/MWh)	**76.3**	**105.6**	**74.0**	**110.3**	**81.3**	**119.4**
CO_2 Avoided B v A ($/ton)	-	54	-	68	-	77
CO_2 Avoided B v SCPC ($/ton)	-	82	-	91	-	108

[1]Total Plant Capital Cost (Includes contingencies and engineering fees but not owner's costs)
[2]80% Capacity Factor, 17.73% Capital Charge Factor, Coal cost $1.64/10^{6}Btu

Plant Cost Comparison

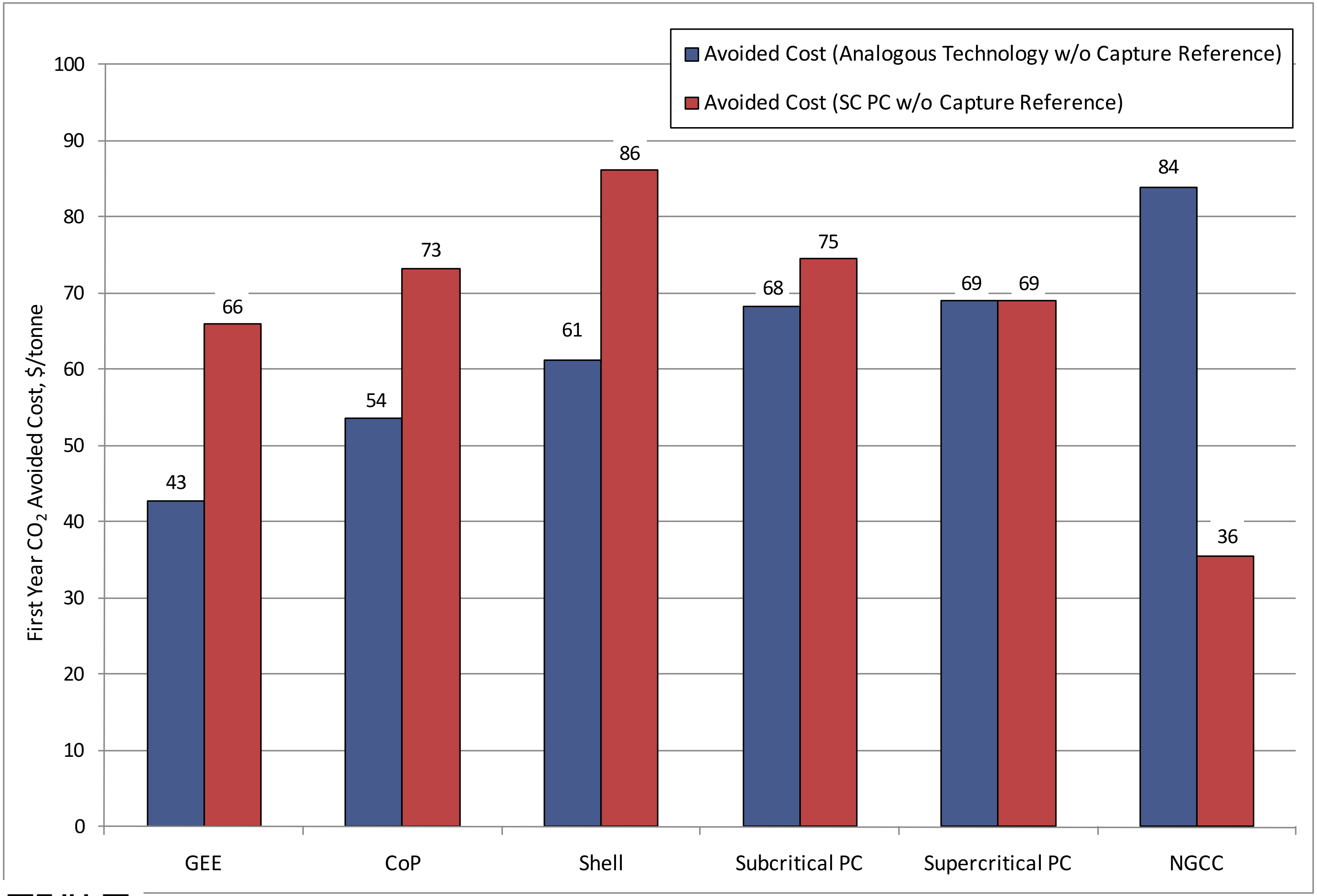


Cost of Electricity Comparison



Coal cost $1.64/10^6 Btu, Gas cost $6.55/10^6 Btu

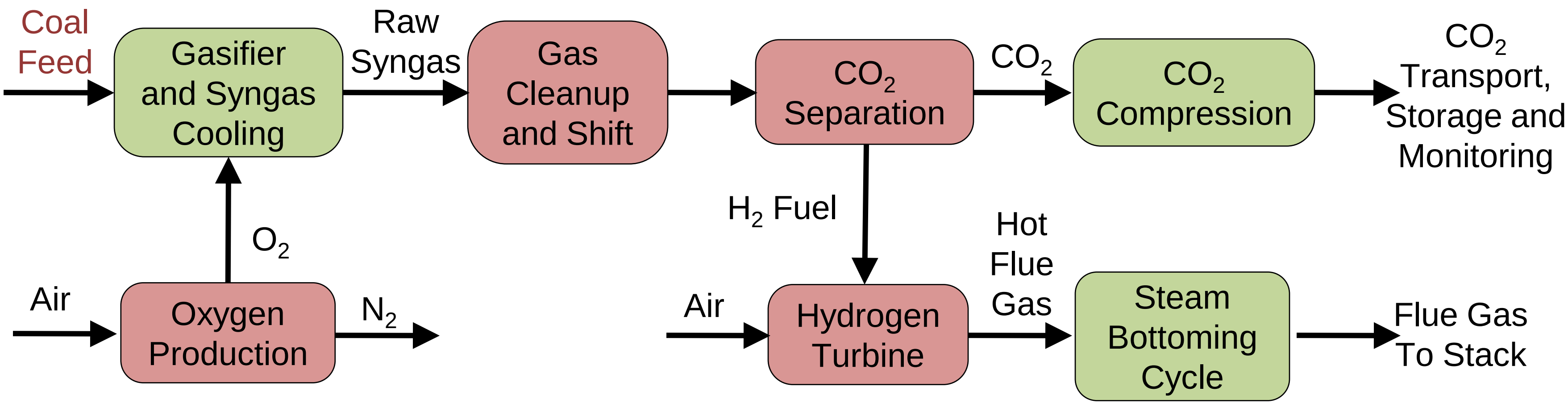
CO_2 Avoided Costs



Systems Analysis

Bituminous IGCC Pathway Study

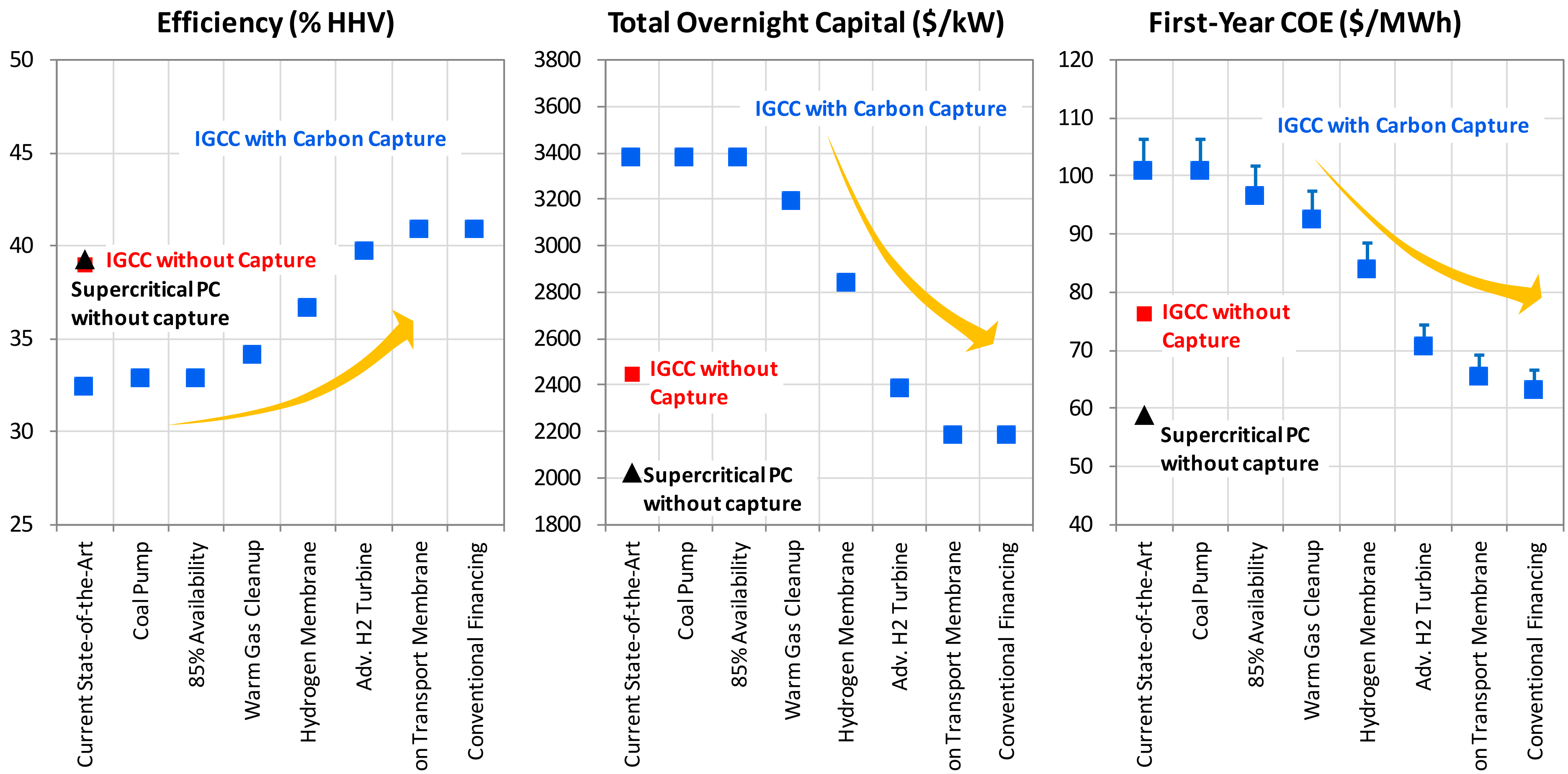
IGCC Advanced Technology Assessments

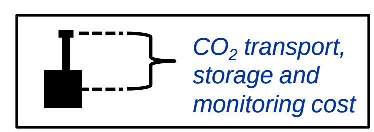


	Technology Advancements				
Coal Feed System	Slurry Feed		→		Coal Feed Pump
Oxygen Production	Cryogenic Air Separation		→		Ion Transport Membrane
Gas Cleanup	Selexol		→		Warm Gas Cleanup
Turbine	Adv F Turbine	→	Adv H_2 Turbine	→	Next Gen Adv Turbine
CO_2 Separation	Selexol		→		H_2 Membrane
Capacity Factor	80%	→	85%	→	90%

Advanced IGCC Systems

Driving Down the Cost

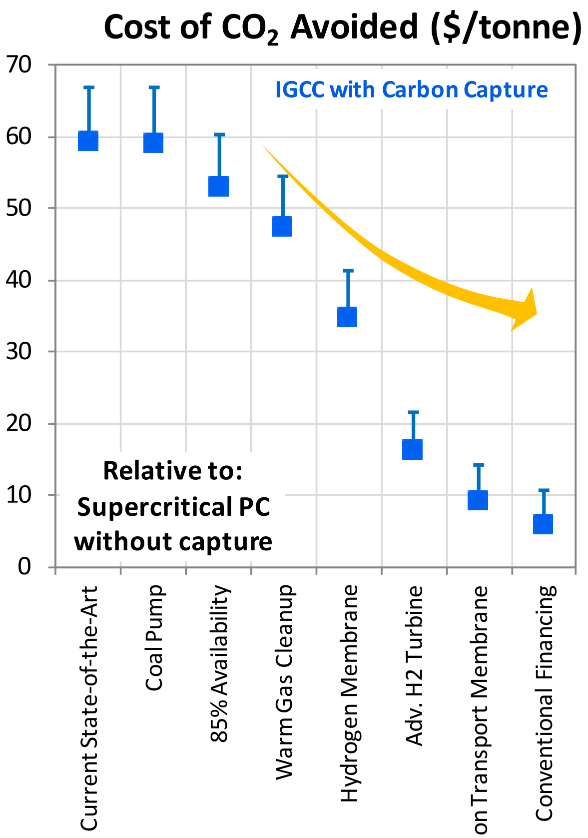


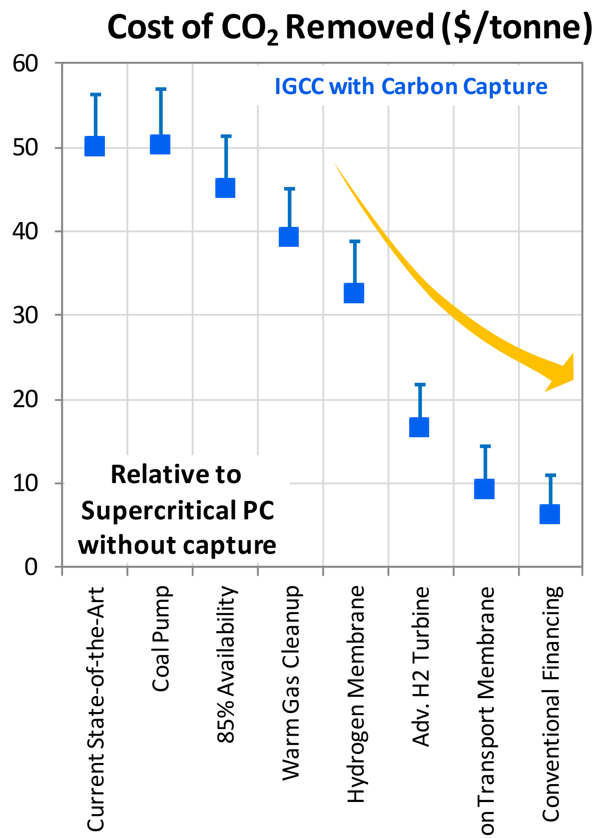


PRELIMINARY RESULTS – SUBJECT TO CHANGE

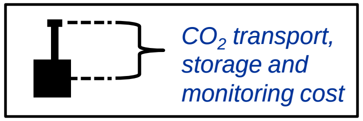
Advanced IGCC Systems

Driving Down the Cost





- CO_2 emissions value to incentivize CCS drops from $65 to $10 per tonne with successful R&D
  - Measured by cost of CO_2 avoided with CO_2 TS&M
- CO_2 power plant gate sales price for CO_2-EOR to incentivize CCUS drops from $50 to $5 per tonne with successful R&D
  - Measured by cost of CO_2 removed excluding CO_2 TS&M

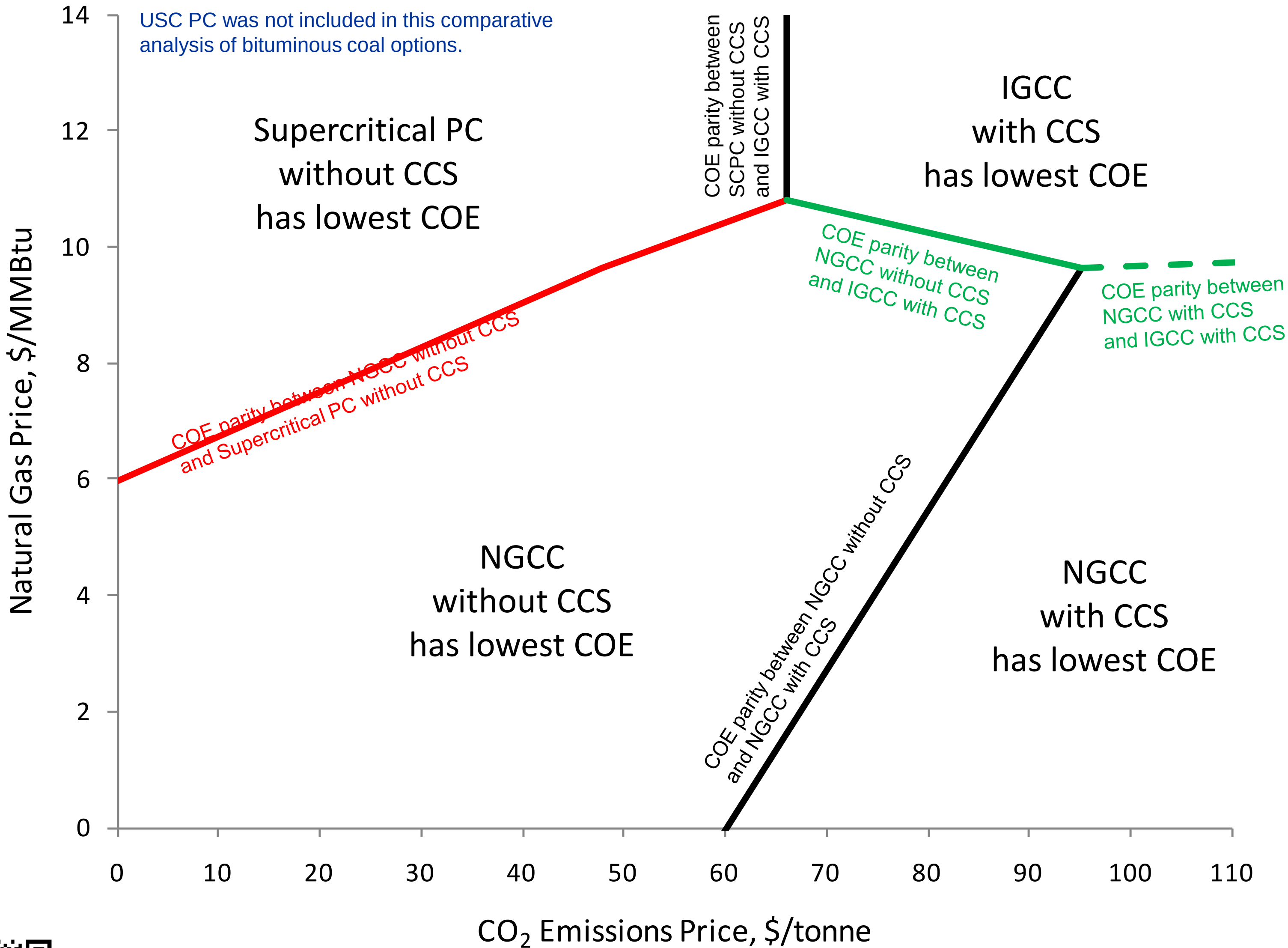


TS&M: Transportation, storage, and monitoring

PRELIMINARY RESULTS – SUBJECT TO CHANGE

Lowest Cost Power Generation Options

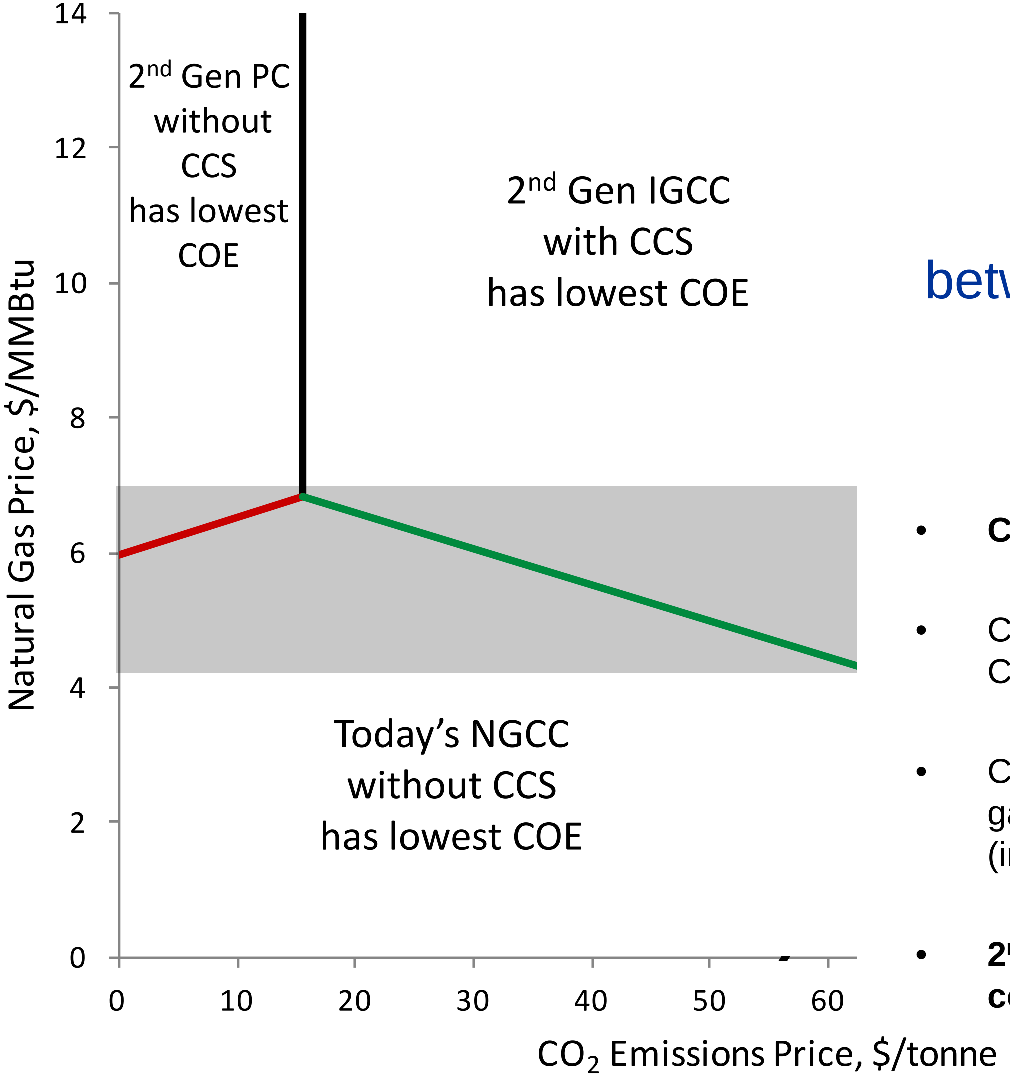
MIDWEST (sea level): *Today's NGCC versus Today's Coal (Bituminous)*



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).
Assumes bituminous coal at delivered price of $1.64/MMBtu

Lowest Cost Power Generation Options

MIDWEST (sea level): *Today's NGCC versus 2nd Generation Coal (Bituminous)*



Given a first-year CO_2 emission price between $0 and $60/tonne, ***and using 2nd-Gen technology***:

- **CCS becomes economically viable**
- Coal with CCS is preferred at first-year CO_2 prices of $15/tonne or higher
- Coal is preferred over natural gas at gas prices above $7/MMBtu (instead of $11/MMBtu)
- **2nd-Gen technology for natural gas could increase CCS market space**

Assumes capacity factor = availability (i.e. all plants including NGCC are base load).
Assumes coal price of $1.64/MMBtu

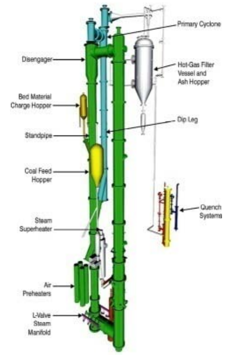
PRELIMINARY RESULTS – SUBJECT TO CHANGE

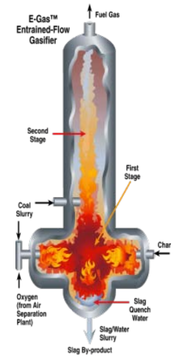
Systems Analysis

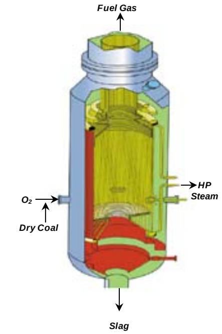
Low Rank Coal Baseline Study: IGCC Cases

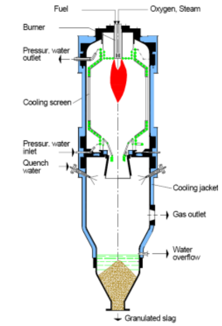
Full presentation available at:
http://www.netl.doe.gov/energy-analyses/baseline_studies.html

IGCC Cases: Technical Design Basis



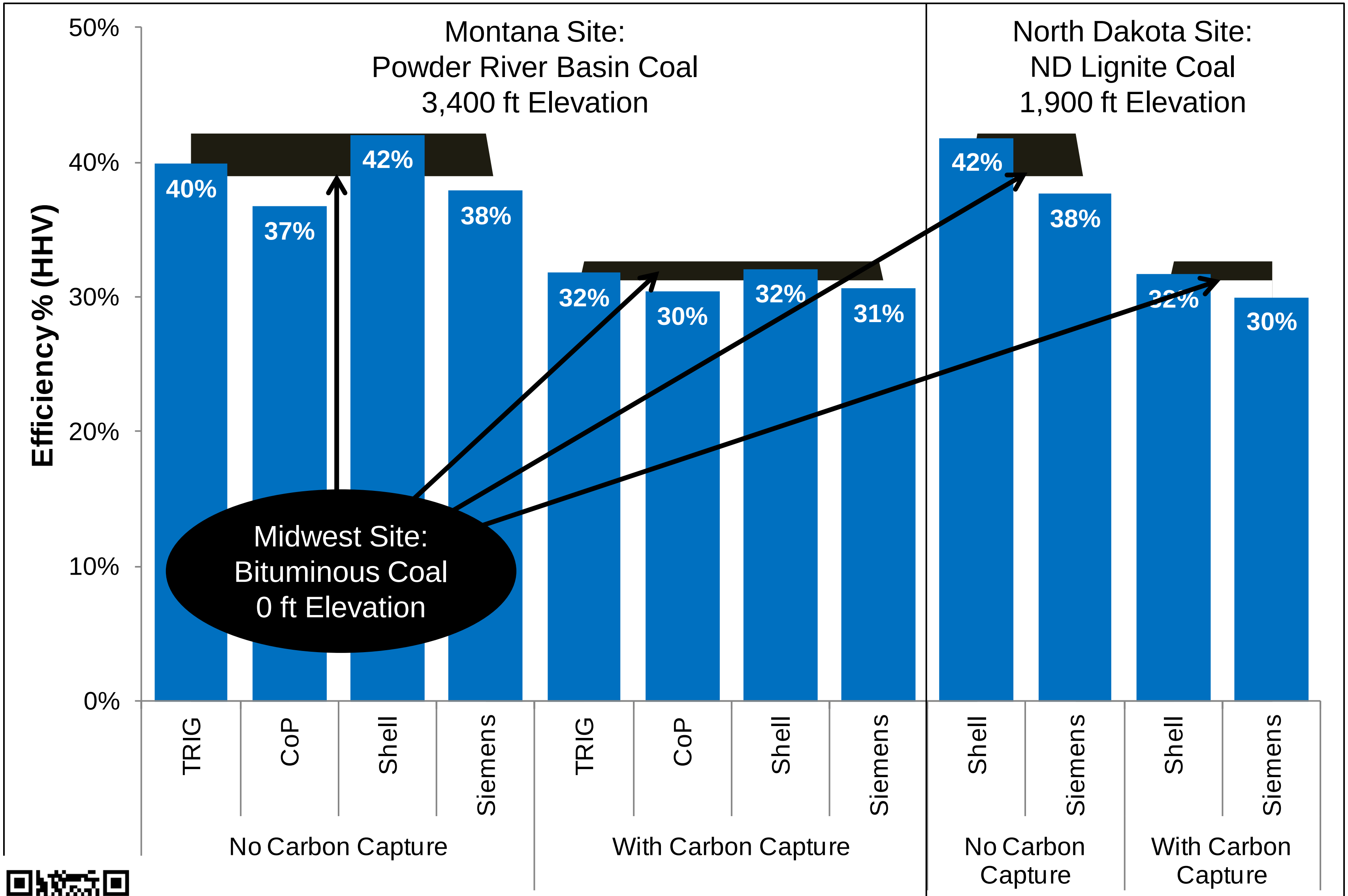




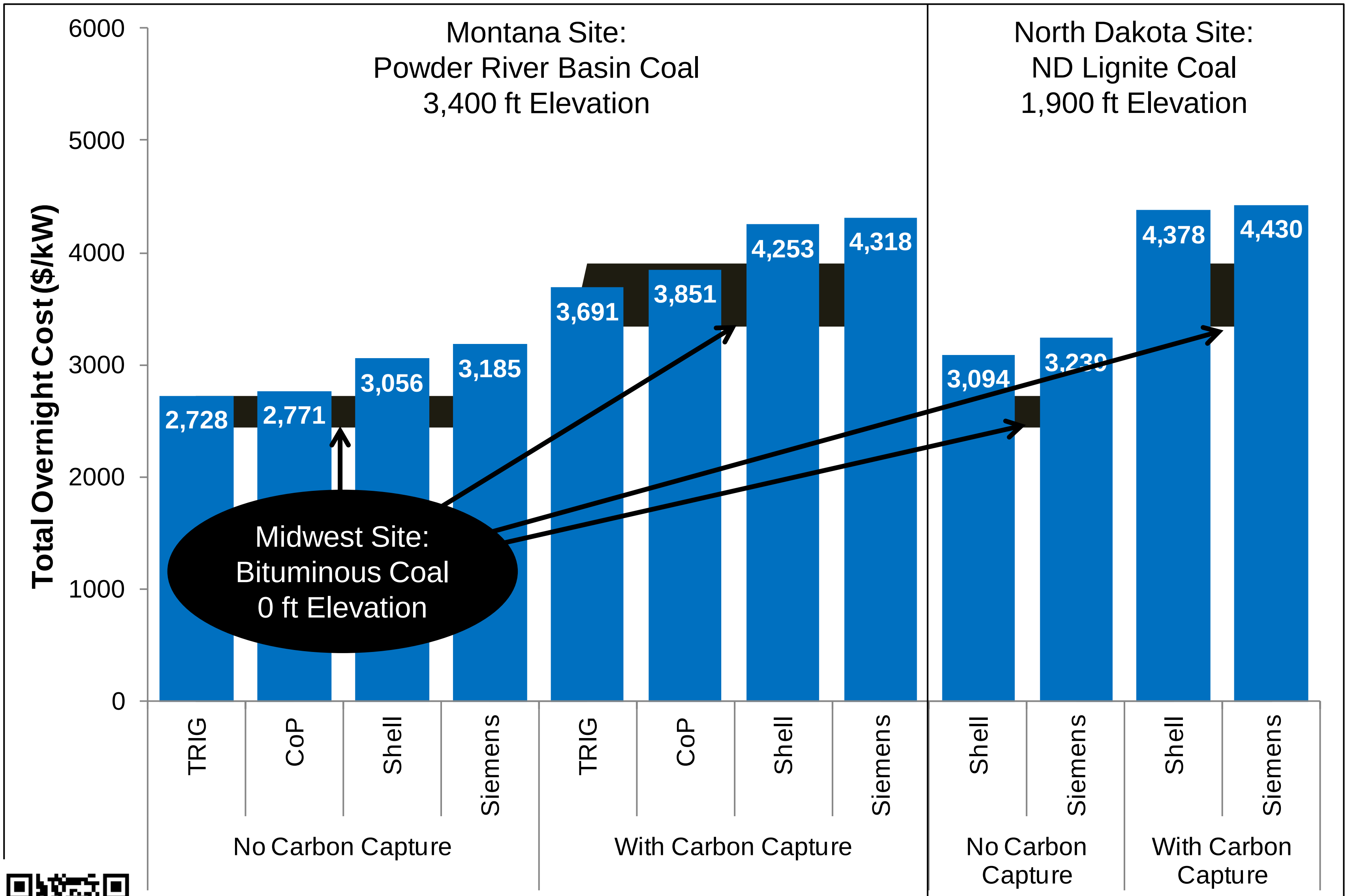


	Southern Company TRIG	ConocoPhillips E-Gas	Shell SCGP	Siemens (GSP/Noell)
Gasifier	Transport	Slurry; entrained	Dry-fed entrained	
Coal Type	PRB		PRB & ND Lignite	
Location/Elevation	Montana/3400 ft		PRB: Montana/3400 ft Lignite: ND/1900 ft	
Coal Drying	Indirectly heated fluidized bed	NA	WTA process	
Oxidant	Oxygen			
AGR for CO2 capture plants	2-Stage Selexol			
Gas Turbine	Advanced F-class (Nitrogen dilution and air integration maximized)			
Steam Cycle (psig/F/F)	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)			
Carbon Capture	83%	90%		
Availability	80%			

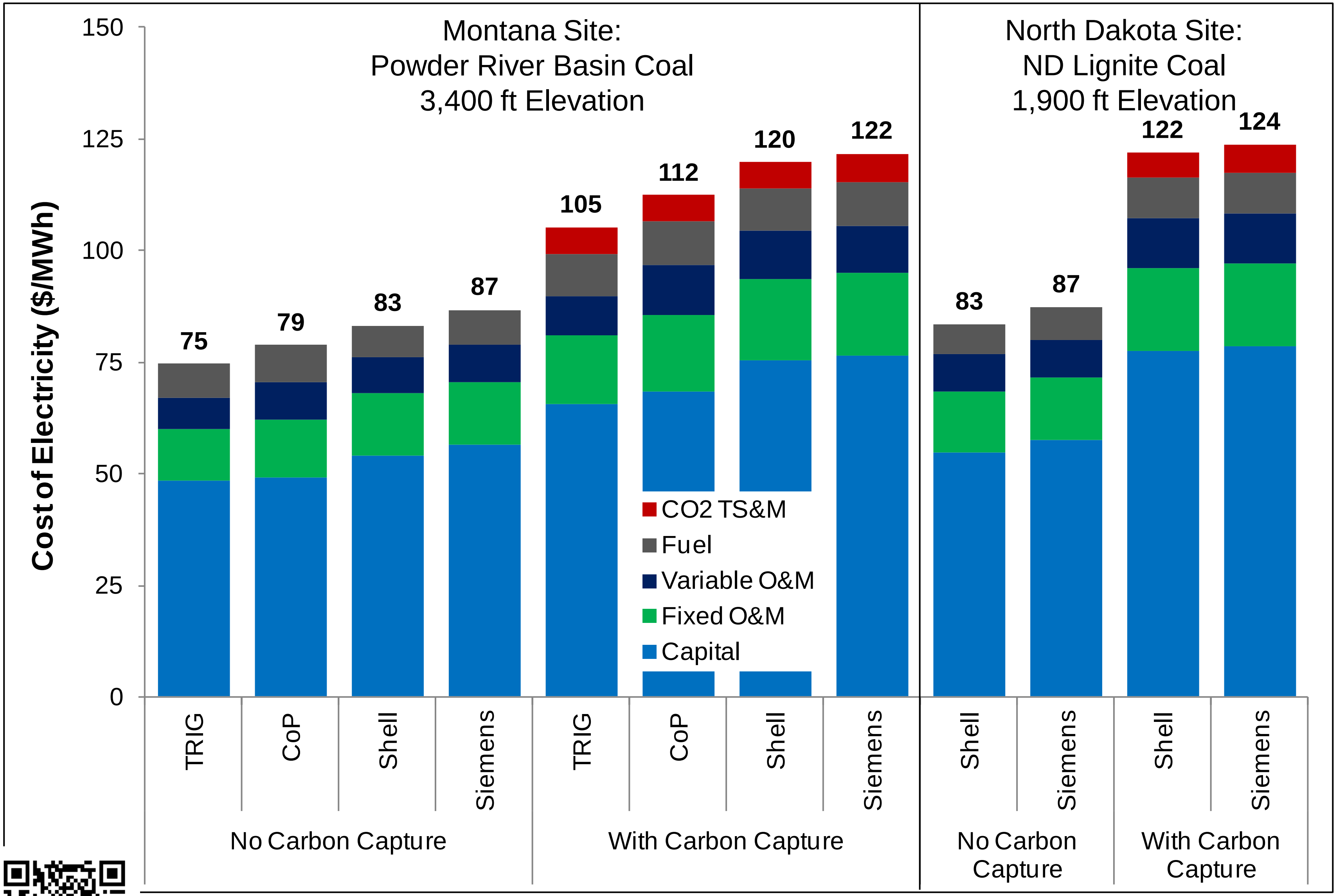
IGCC Efficiency: Bituminous Coal Comparison



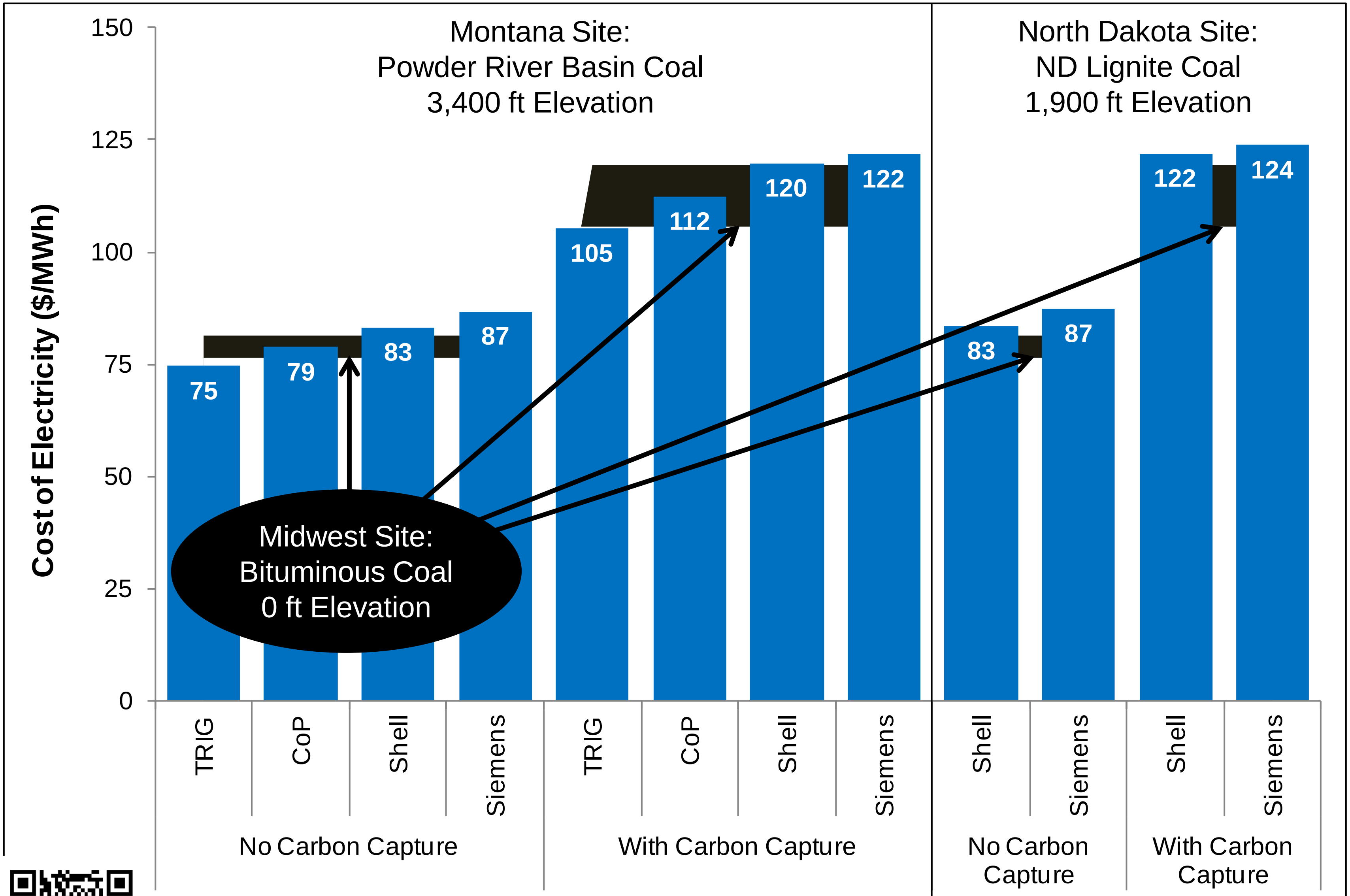
IGCC Plant Cost: Bituminous Coal Comparison



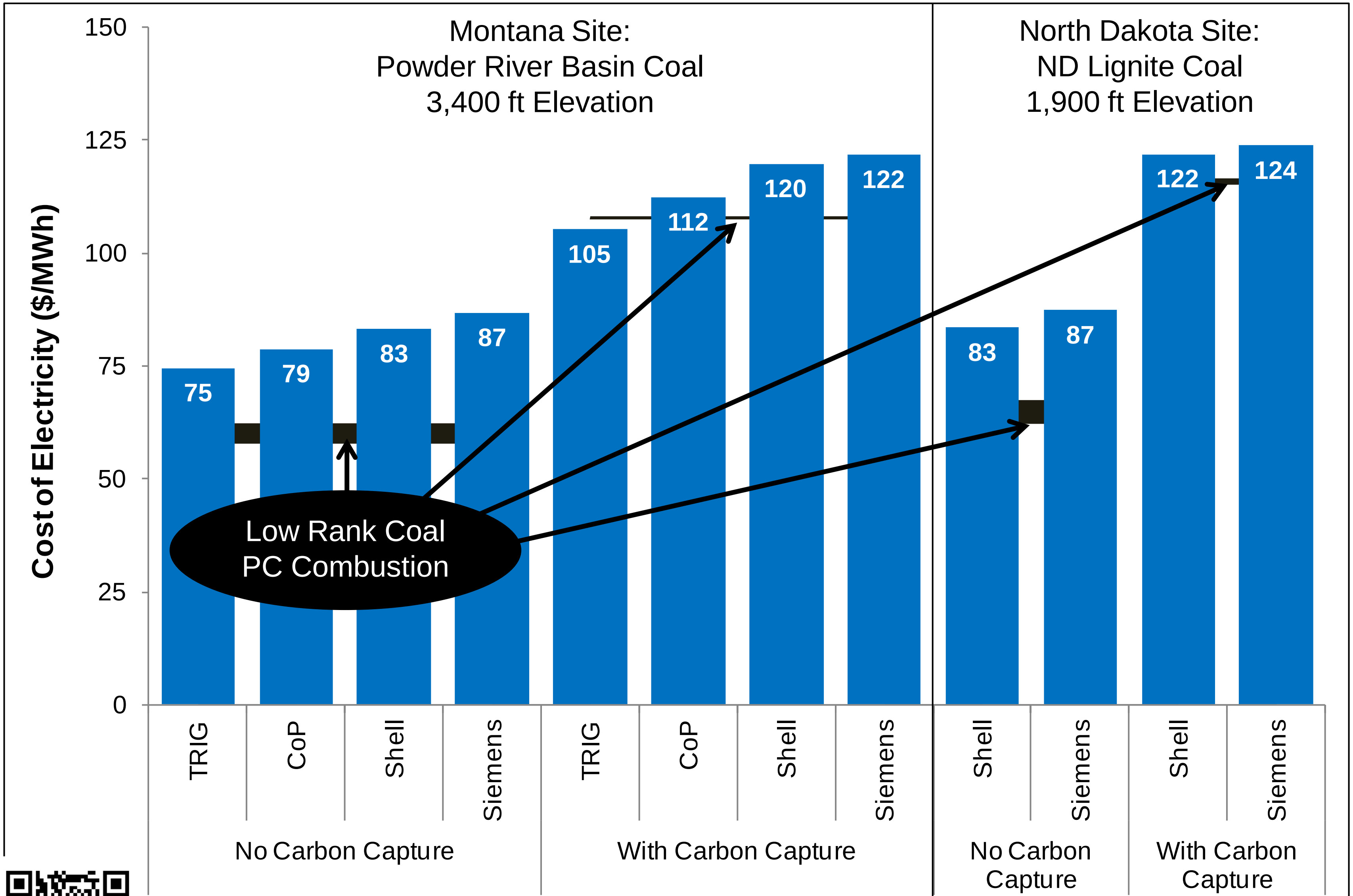
Conventional IGCC: COE



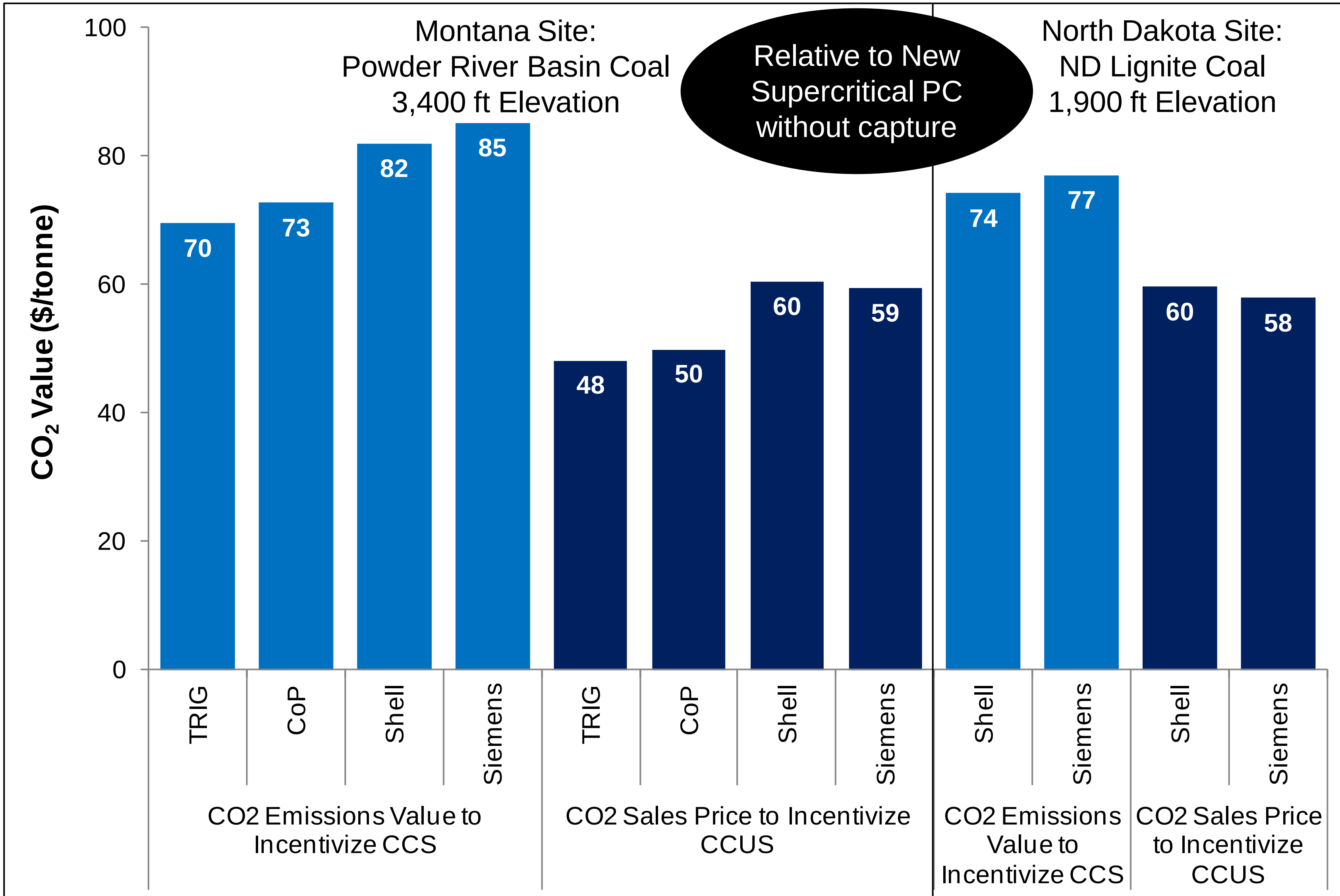
IGCC COE: Bituminous Coal Comparison



IGCC COE: Comparison to PC Plants



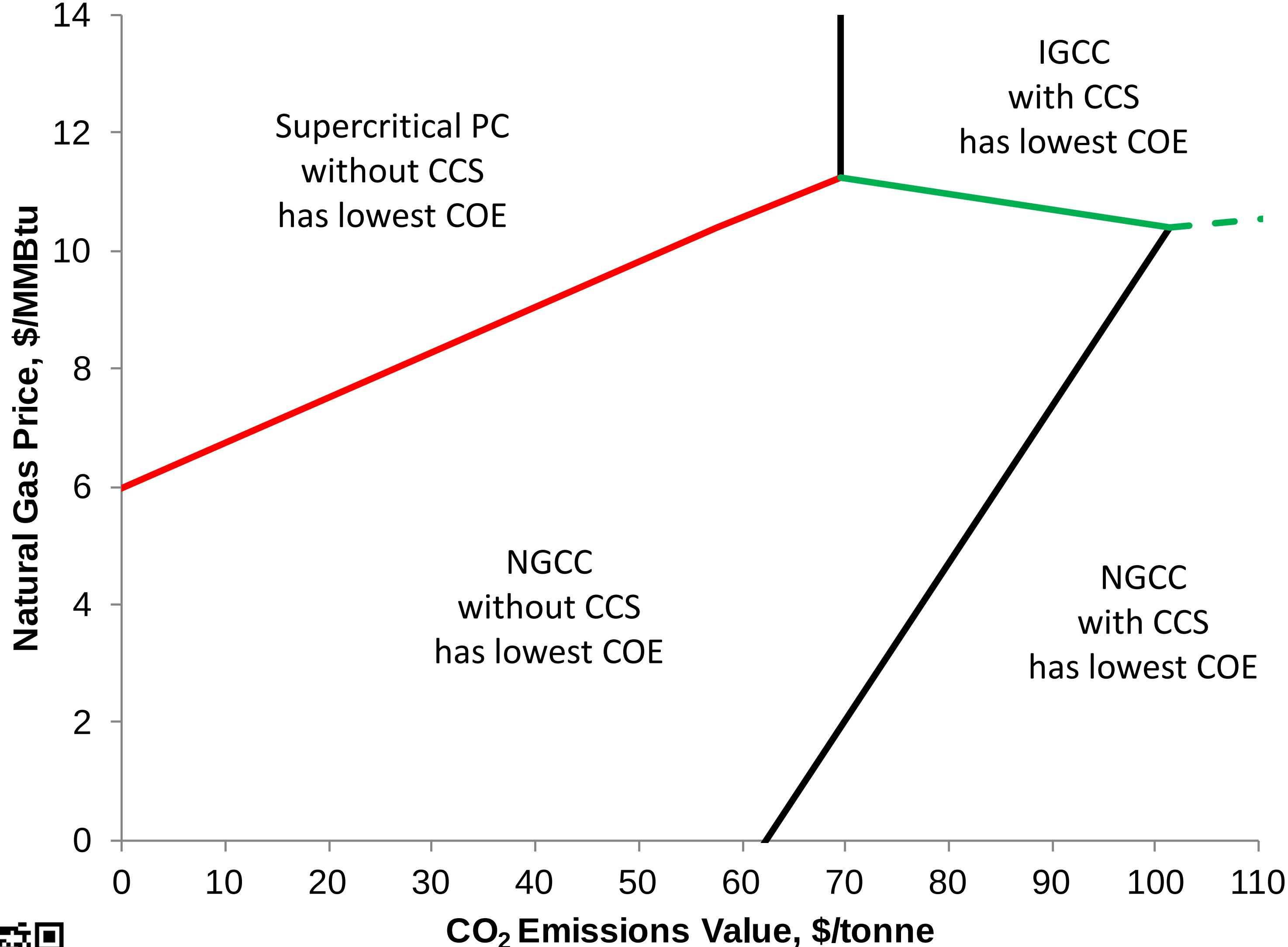
Conventional IGCC: CO_2 Capture Cost



CCUS = Carbon capture, utilization and storage

Lowest Cost Power Generation Options

Western (3400 ft): Today's NGCC versus Today's Coal (PRB)



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).

Key Findings & Next Steps

Transport gasifier provides low cost IGCC power
Slurry-fed gasification still competitive for high-moisture PRB coal
Western location/low rank coal gasification COE on par with midwest/bituminous coal gasification
IGCC with carbon capture COE essentially equivalent to PC PRB
All coal systems, with and without carbon capture, face challenges competing in today's U.S. market

- No carbon policy
- Current natural gas prices

Opportunities for IGCC

- State-of-the-Art: Co-production, CO_2 utilization via enhanced oil recovery
- 2nd Gen: R&D and demonstration for advanced technologies

Systems Analysis

Low Rank Coal IGCC Pathway Study

Systems Analyses for Advanced IGCC

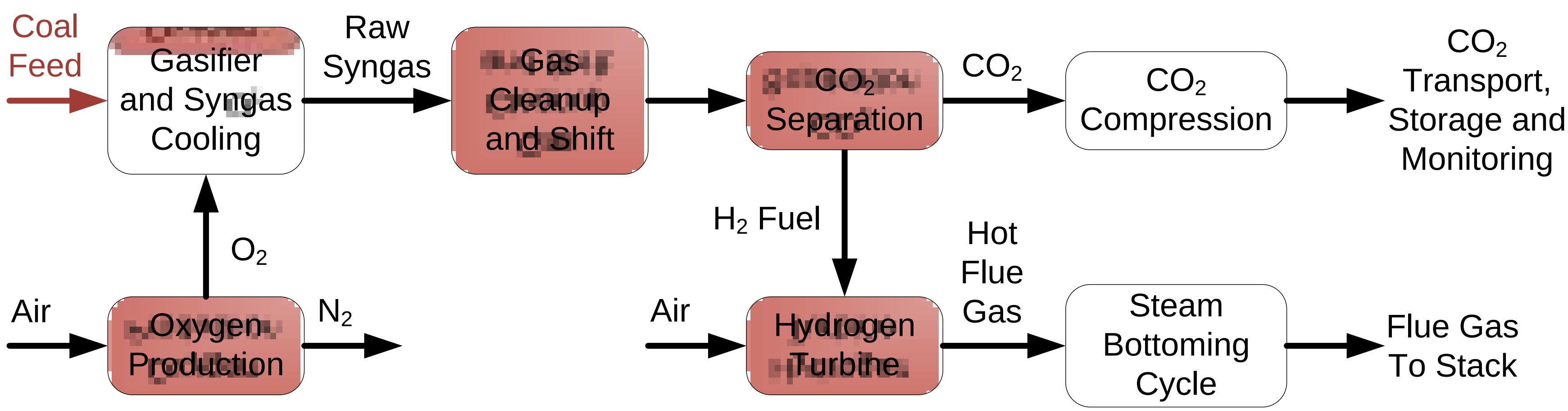
Objectives:

- Evaluate improved performance and cost resulting from DOE-funded R&D
- Identify enabling technologies within the portfolio
- Show relative contribution of different R&D efforts
- Identify/highlight gaps for low rank coal R&D pathway

Approach:

- Begin with established cost and performance of conventional IGCC
  - CoP E-Gas selected as reference plant
- Substitute conventional technologies with advanced technologies in a cumulative fashion assuming successful R&D
- Evaluate cost and performance in a manner consistent with baseline studies

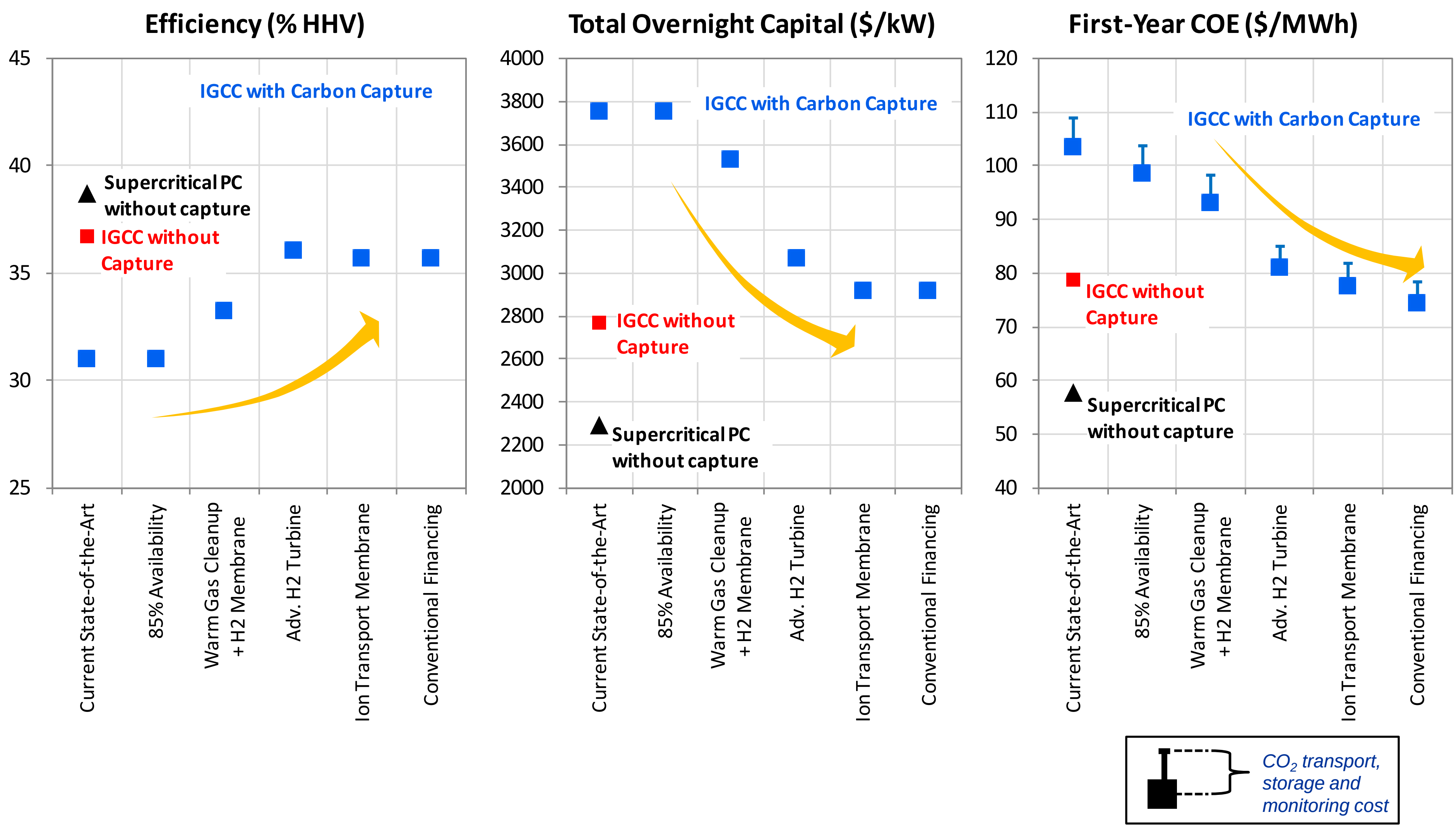
Advanced Technology Progression



	Technology Progression				
Gas Cleanup	Physical Solvent		→		Warm Gas Cleanup (WGCU)
CO_2 Separation	Physical Solvent		→		H_2 Membrane
Gas Turbine	Advanced F-Class		→		Advanced Hydrogen Turbine
Oxygen Production	Cryogenic Air Separation		→		Ion Transport Membrane (ITM)
Availability	80%	→	85%	→	90%

Advanced IGCC Systems – PRB Coal

Driving Down the Cost

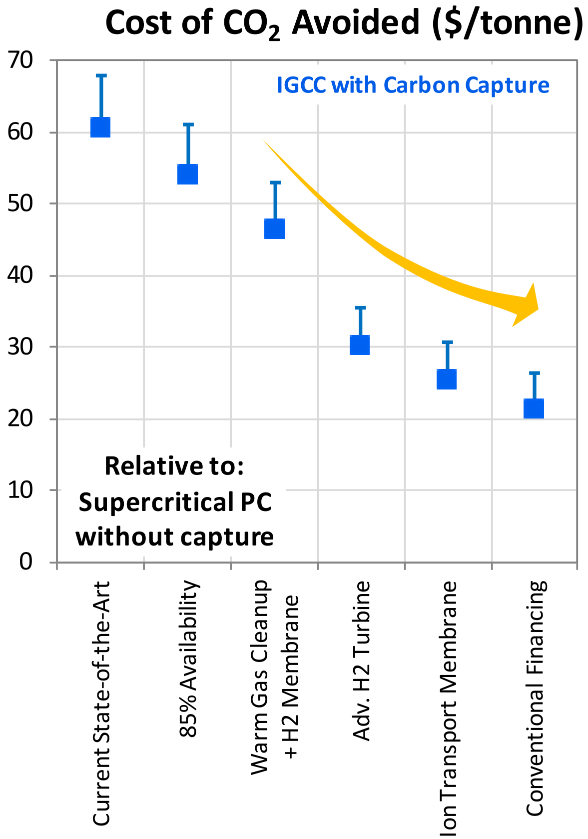


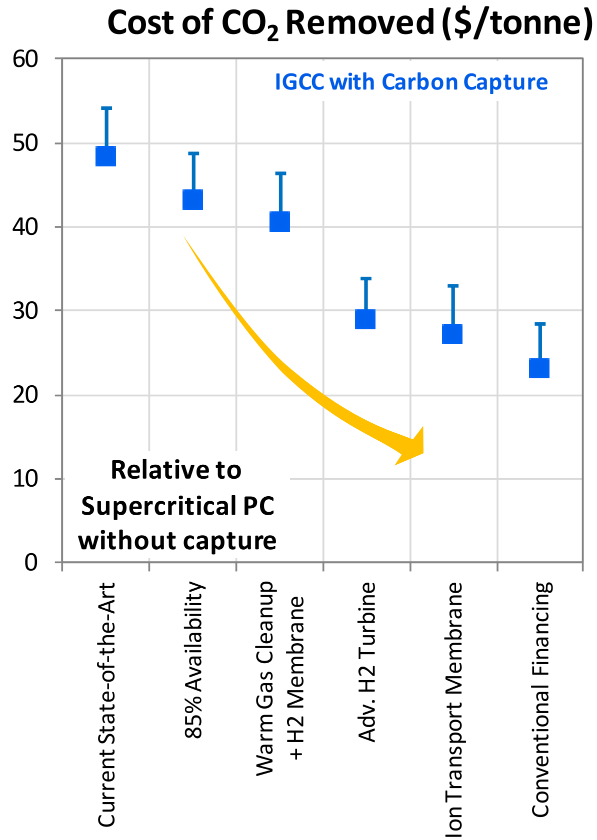
NATIONAL ENERGY TECHNOLOGY LABORATORY

PRELIMINARY RESULTS – SUBJECT TO CHANGE

Advanced IGCC Systems – PRB Coal

Driving Down the Cost





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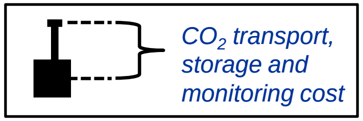
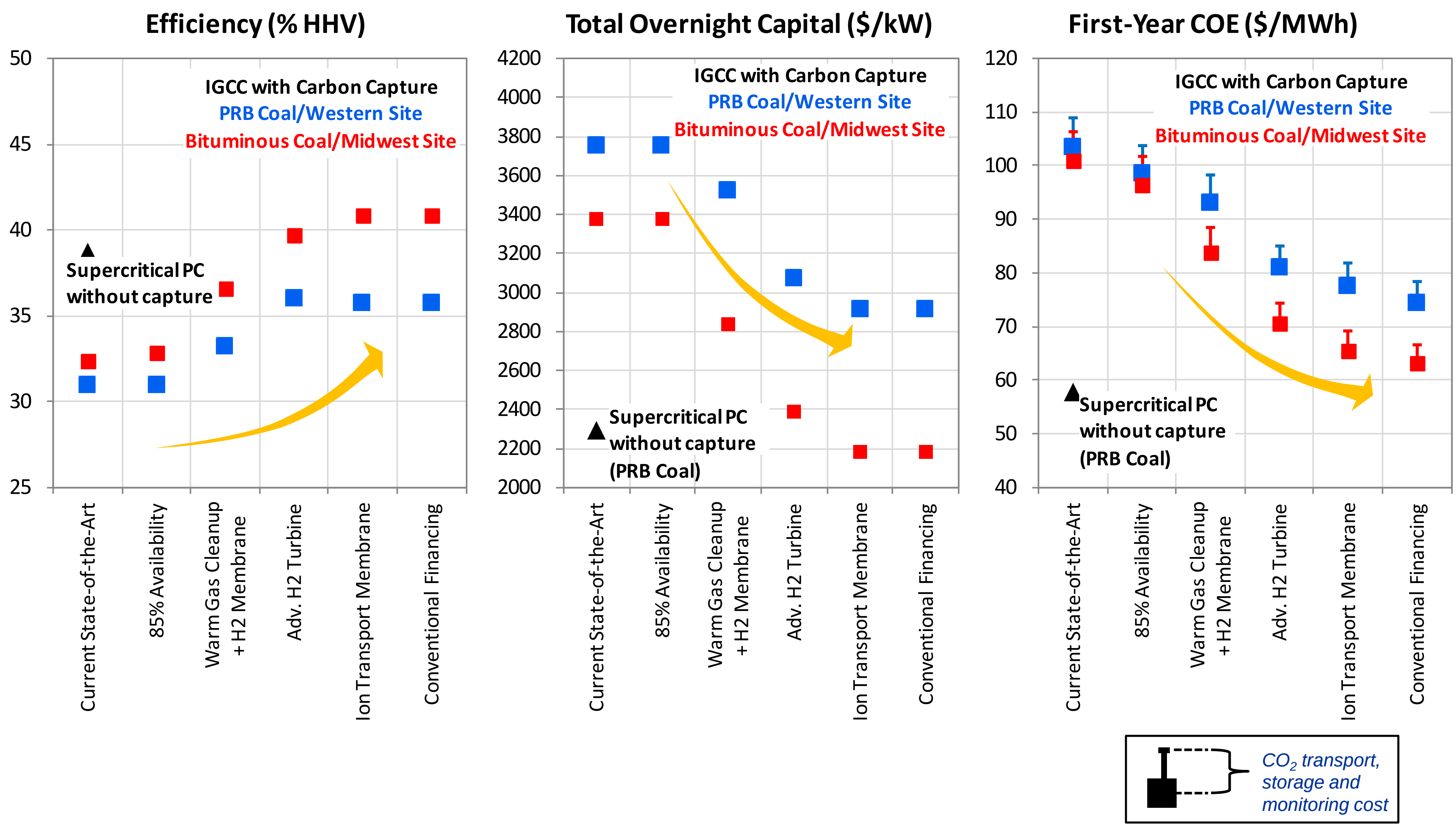


PRELIMINARY RESULTS – SUBJECT TO CHANGE

Advanced IGCC Systems

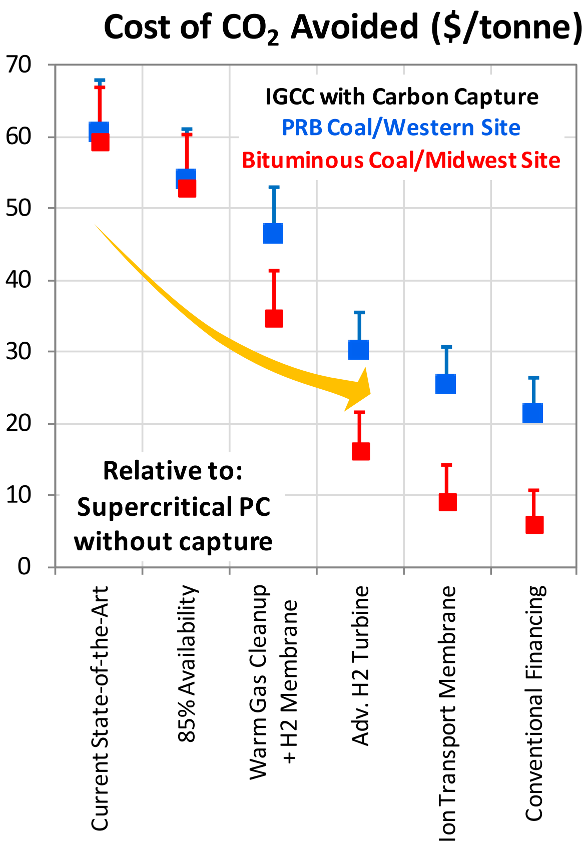
Driving Down the Cost

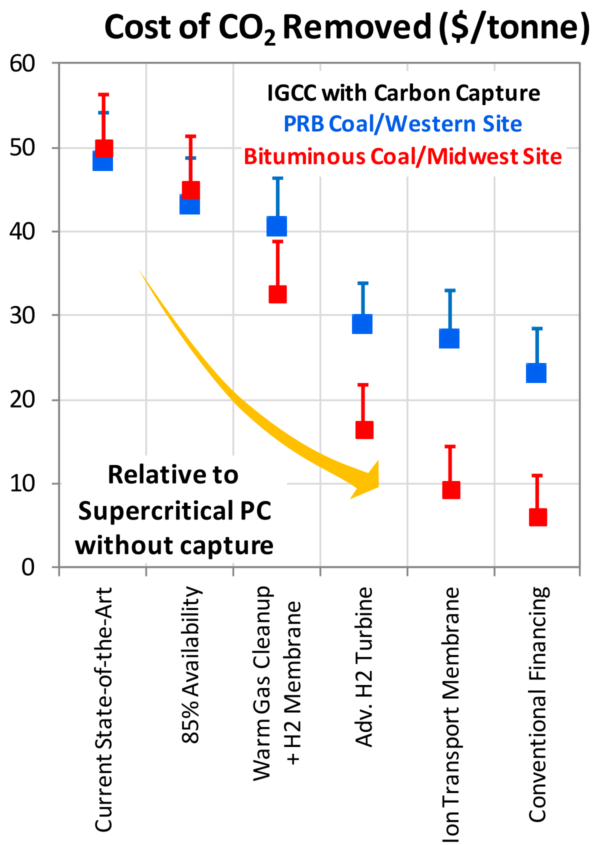


PRELIMINARY RESULTS – SUBJECT TO CHANGE

Advanced IGCC Systems

Driving Down the Cost





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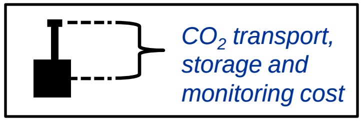
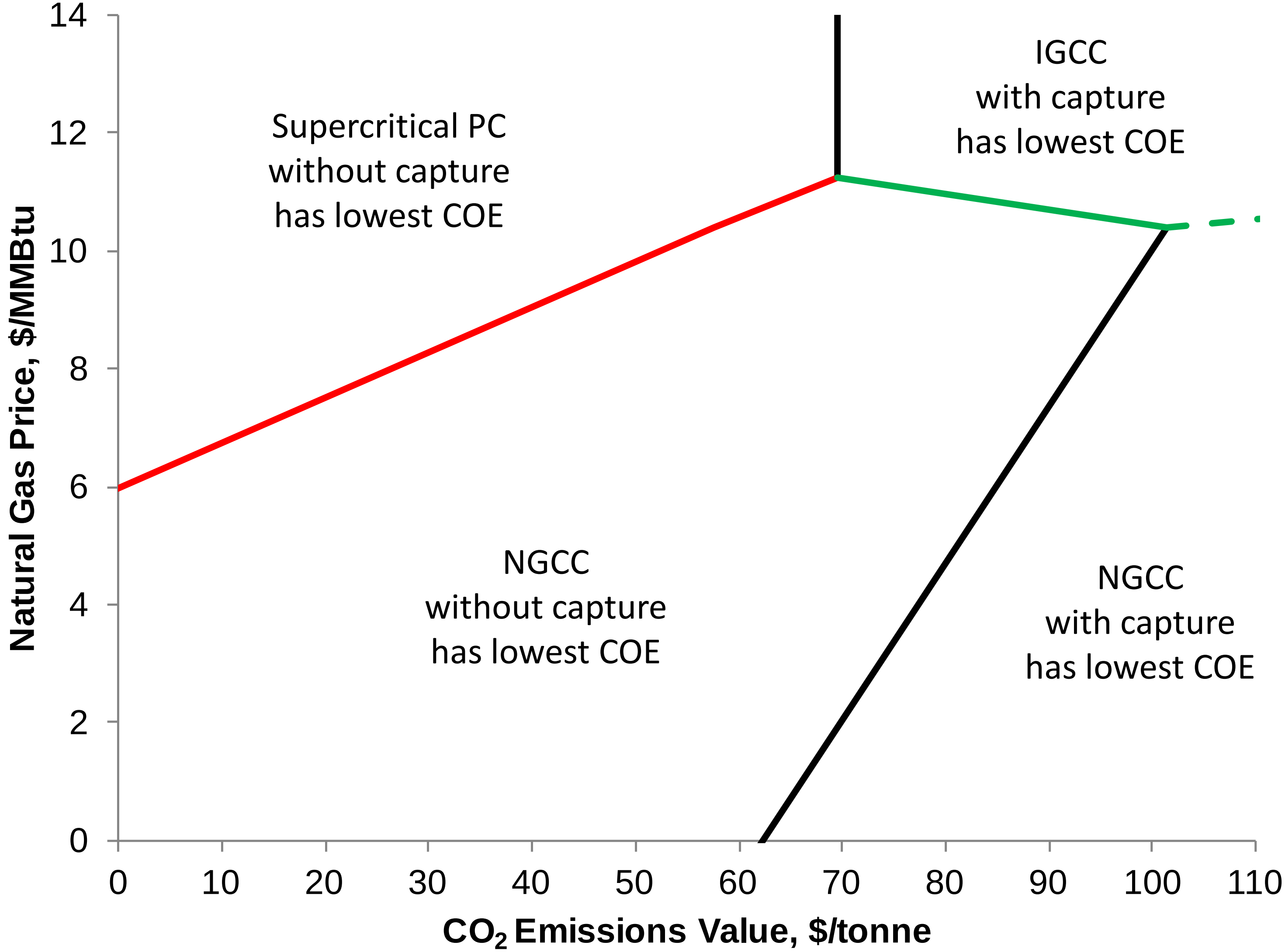


PRELIMINARY RESULTS – SUBJECT TO CHANGE

Lowest Cost Power Generation Options

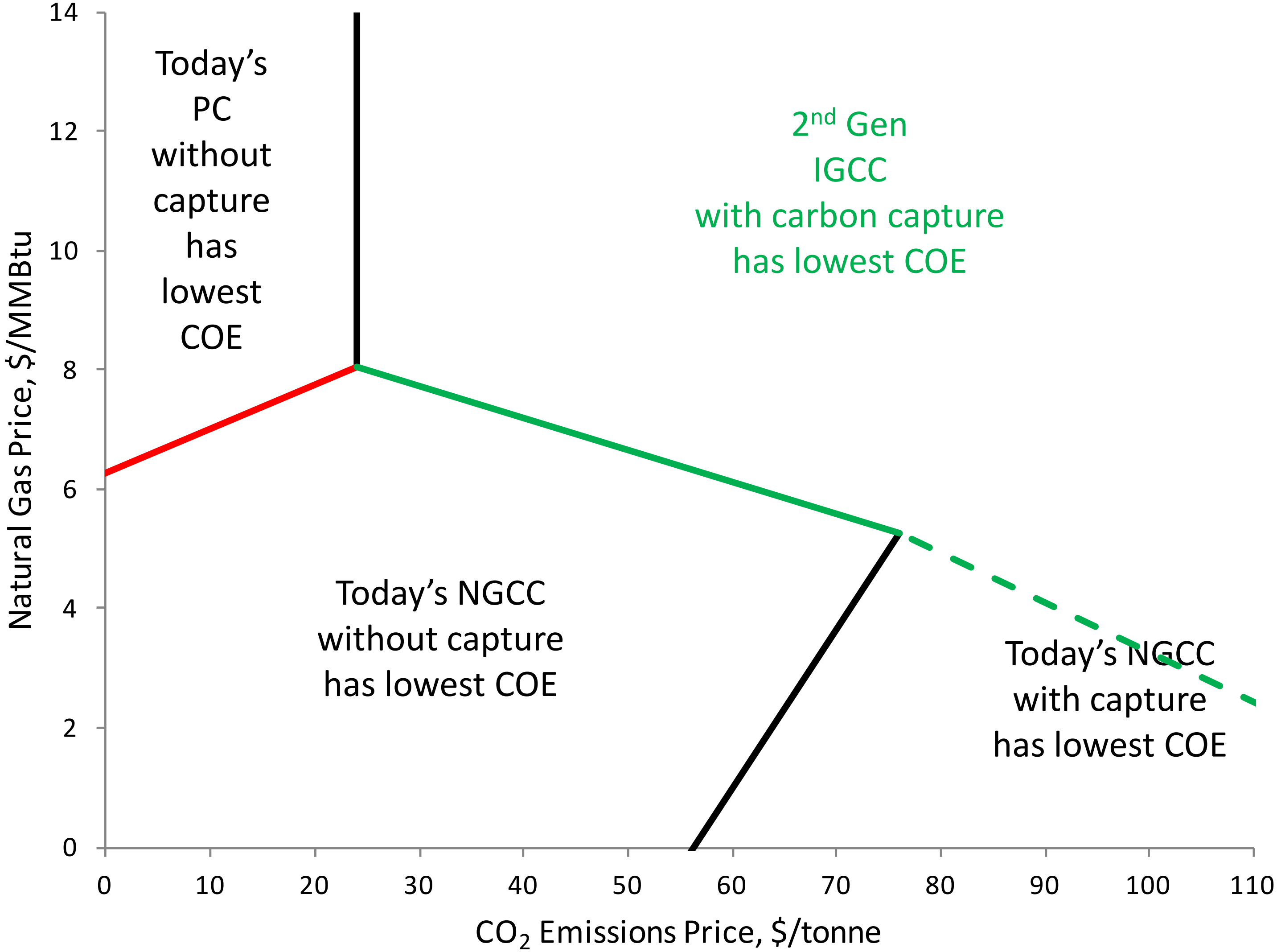
Western (3400 ft): Today's NGCC versus Today's Coal (PRB)



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).

Lowest Cost Power Generation Options

Western (3400 ft): Today's NGCC versus 2nd Gen IGCC (PRB)



Assumes capacity factor = availability (i.e. all plants including NGCC are base load).

Findings of Study and Gaps

- **Current DOE portfolio provides 5 points efficiency gain, 30% reduction in COE relative to today's IGCC with CCS**
- **High pressure gasification may be needed to enable advanced technologies in current R&D portfolio**
  – Managing WGCU pressure drop, hydrogen membrane driving force, meeting fuel gas pressure needs for advanced hydrogen turbine
- **Evaluation of alternatives to slurry-fed gasification for 2^{nd} Gen IGCC recommended**

Conventional IGCC Compared to PC and NGCC

Fundamental Comparison of IGCC with Advanced PC-Fired Plant

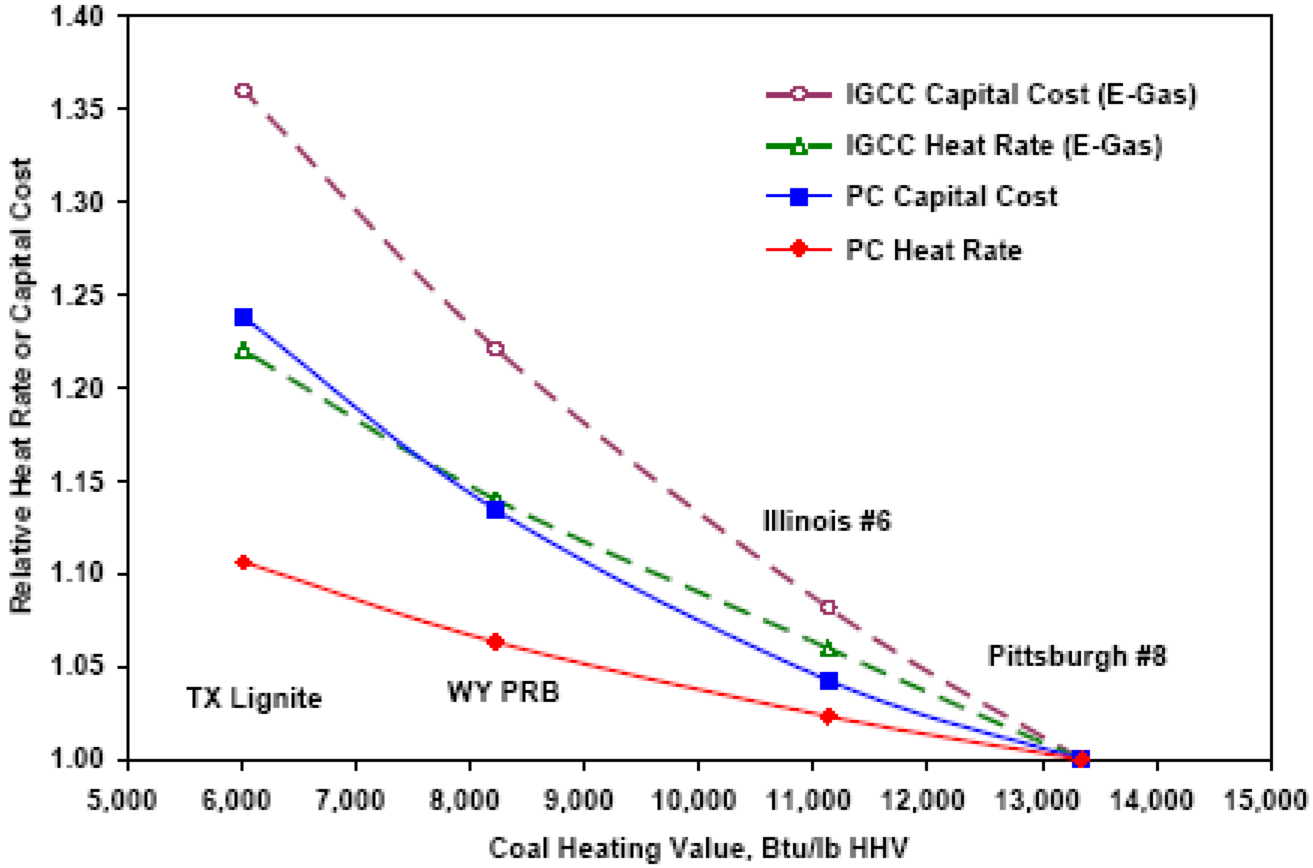
		IGCC
PC		
Operating Principles	Partial Oxidation	Full Oxidation
Fuel Oxidant	Oxygen	Air
Temperature	≤ 3000 F	≤ 3200 F
Pressure	415-1000 psia	Atmospheric
Sulfur Control	Concentrate Gas	Dilute Gas
Nitrogen Control	Not Needed	Pre/Post Combustion
Ash Control	Low Vol. Slag	Fly/Bottom Ash
Trace Elements	Slag Capture	ESP/Stack
Wastes/By-products	Several Markets	Limited Markets
Efficiency (HHV)	39-42%	37-40%

Comparison of Air Emission Controls: PC vs. IGCC

	Sulfur	NO_x	PM	Mercury
PC Post Combustion	FGD system	Low-NO_x burners and SCR	ESP or baghouse	Inject activated carbon
IGCC Pre Combustion	Chemical and/or physical solvents	Syngas saturation and N_2 diluent for GT and SCR	Wet scrubber, high temperature cyclone, barrier filter	Pre-sulfided activated carbon bed

Steve Jenkins 2009 GTC Workshop http://www.gasification.org/uploads/downloads/Workshops/2009/Kingsport/02Jenkins.pdf

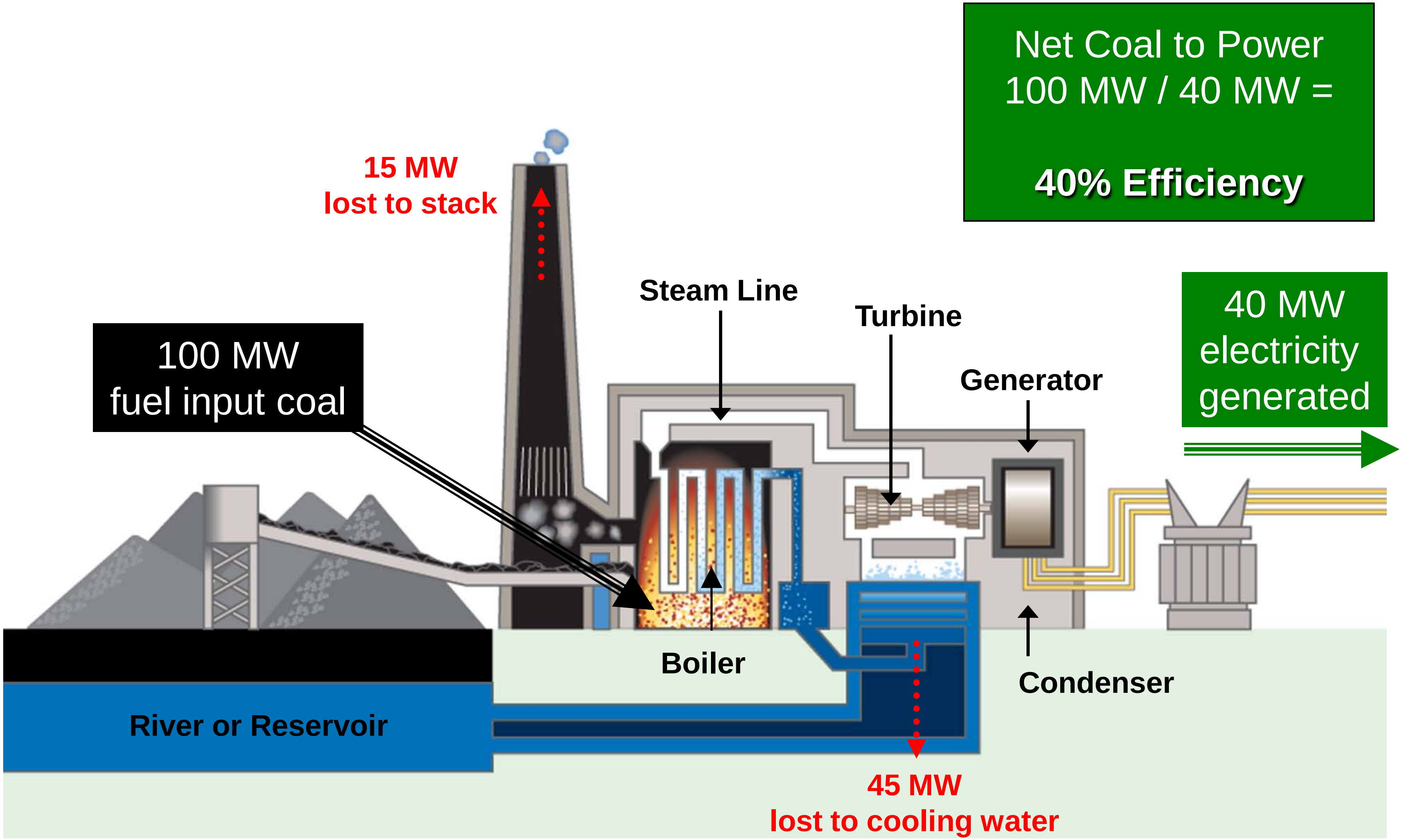
Effect of Coal Quality on PC and IGCC Plant Heat Rates and Capital Costs



Source: EPRI (Booras and Holt), "Pulverized Coal and IGCC Plant Cost and Performance Estimates", GTC Conference, October 2004

Conventional Coal Plant

(Illustration only)



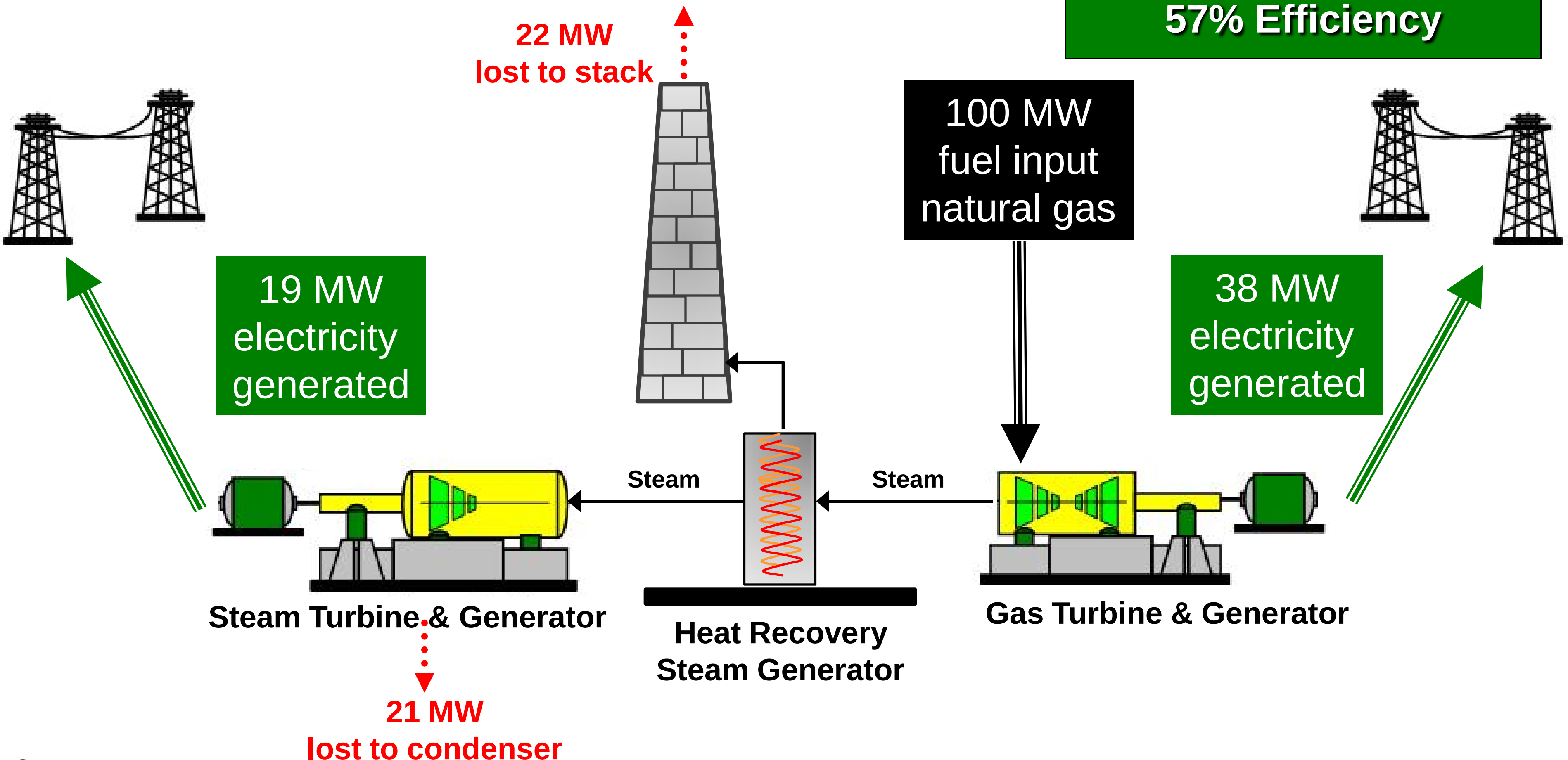
Source: EPRI

Natural Gas Combined Cycle

(Illustration only)

Net Natural Gas to Power
100 MW / (19 + 38) MW =

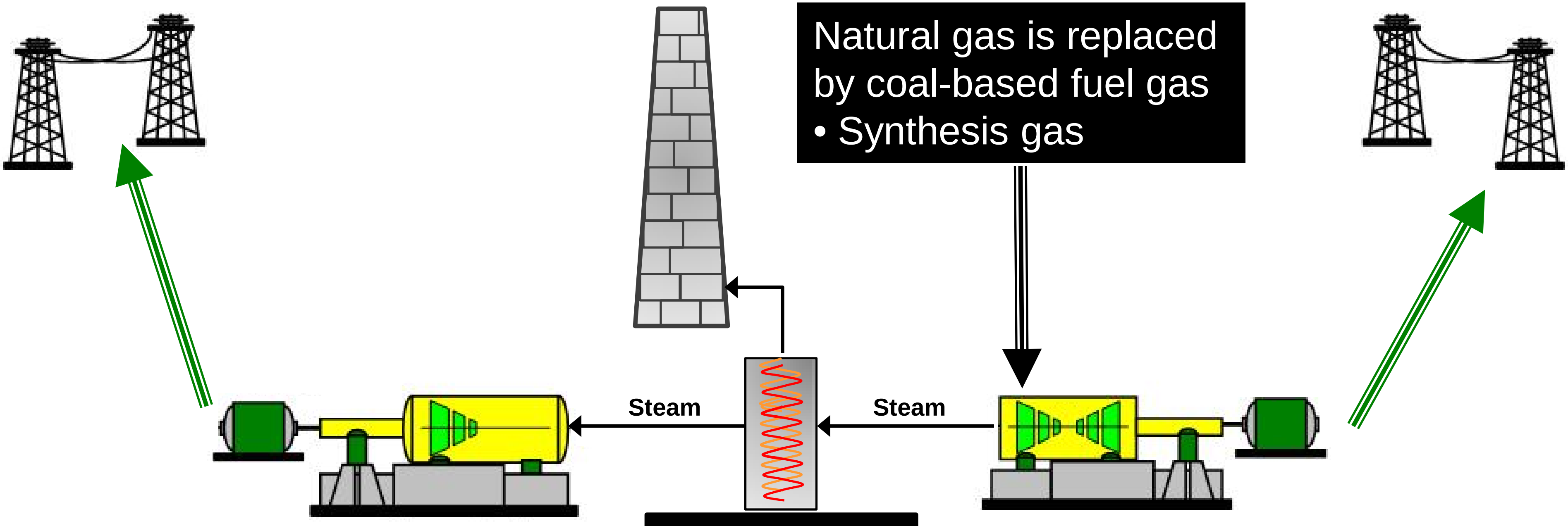
57% Efficiency



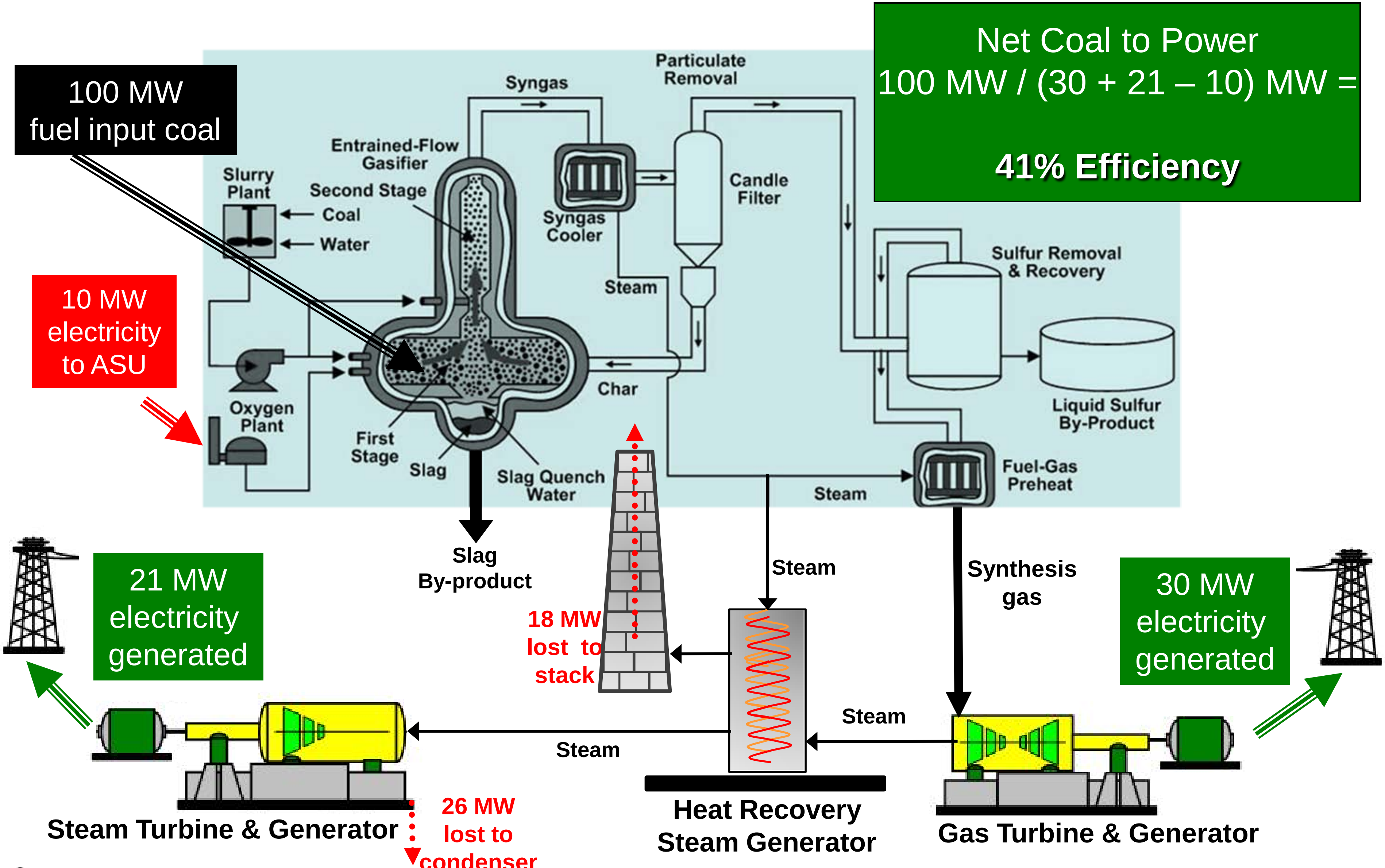
Coal-Based IGCC Power Plant

Gasification Island
- Converts coal to synthesis gas
- Cleans & conditions synthesis gas

Natural gas is replaced by coal-based fuel gas
- Synthesis gas



Coal-Based IGCC Power Plant



Gasification-Based Energy Conversion Systems

RESOURCES

- Air/Oxygen
- Coal
- Biomass
- Petroleum Coke
- Heavy Oil
- Refinery Wastes
- MSW
- Orimulsion
- Other Wastes

GASIFIERS

OXYGEN-BLOWN

Entrained Flow
GE Energy, E-Gas, Shell, Prenflo, Noell, Huaneng CERI, OMB

Fluidized Bed
HT Winkler, U-Gas

Moving Bed
British Gas Lurgi (BGL)
Lurgi (Dry Ash)

Transport Reactor
KBR

AIR-BLOWN

Fluidized Bed
HT Winkler, GTI U-Gas,
KRW

Sprouting Bed
British Coal,
Foster Wheeler

Entrained Flow
Mitsubishi

Transport Reactor
KBR

ENVIRONMENTAL CONTROL

Particulate Removal and Recycle
- Filtration,
- Water Scrubbing

Chloride and Alkali Removal
- Water Scrubbing

Acid Gas Removal
- Amine Processes
- Rectisol, Selexol

COS Hydrolysis

Sulfur Recovery
- Claus Process
- SCOT Process
- Sulfuric Acid Plant

Water Treatment
- Process Water, BFW

Tail Gas Treating

Turbine NOx Control
- Nitrogen/Steam Dilution
- SCR

Syngas Mercury Capture

Syngas CO_2 Capture

ENERGY CONVERSION

- Gas Turbine
- Heat Recovery Steam Generator (HRSG)
- Steam Turbine
- Boiler
- Syngas Conversion to Fuels & Chemicals
- Catalytic Conversion
- Shift Conversion
- Fischer-Tropsch
- Fuel Cell
- H_2 Turbine

PRODUCTS

- Steam
- Electric Power
- Liquid Fuels
- Chemicals
- Methanol
- SNG
- Hydrogen
- Ammonia/ Fertilizers
- Slag
- Sulfur/ Sulfuric Acid

Commercial IGCC Plants

Commercial IGCC Plants in the U.S.

Active and Under Construction

(excluding DOE supported demonstration projects)

Wabash River Coal Gasification Repowering Project
262 MWe coal/petcoke (1995 - present)

Tampa Electric Polk Power Station
250 MWe coal/petcoke (1996 - present)

Duke Energy's Edwardsport Integrated Gasification Combined Cycle Station
618 MWe coal (2013 start up)

Wabash River IGCC

SG Solutions − West Terre Haute, Indiana

Plant startup July 1995

E-Gas gasifier
ConocoPhillips

2,500 tons/day coal or petcoke

Bituminous coal
1995 thru August 2000

Petcoke
2000 thru Present

DOE CCT Round IV
Repowering project

Power generation

Combustion turbine:	192 MWe
Steam turbine:	105 MWe
Internal load:	-35 MWe
Net output:	**262 MWe**

Wabash River IGCC Plant Aerial Photo

Polk Power Station Unit 1

Tampa Electric Co. − Mulberry, FL

GE Gasifier

Oxygen blown

Slurry fed

Entrained flow

Refractory lined

Feedstock 2,200 tons/day

Coal and petcoke blend

CT is GE 7F

Single train configuration

One gasifier supplying one CT

Acid gas removal via

MDEA and COS hydrolysis

DOE Clean Coal Technology Program

Plant startup July 1996

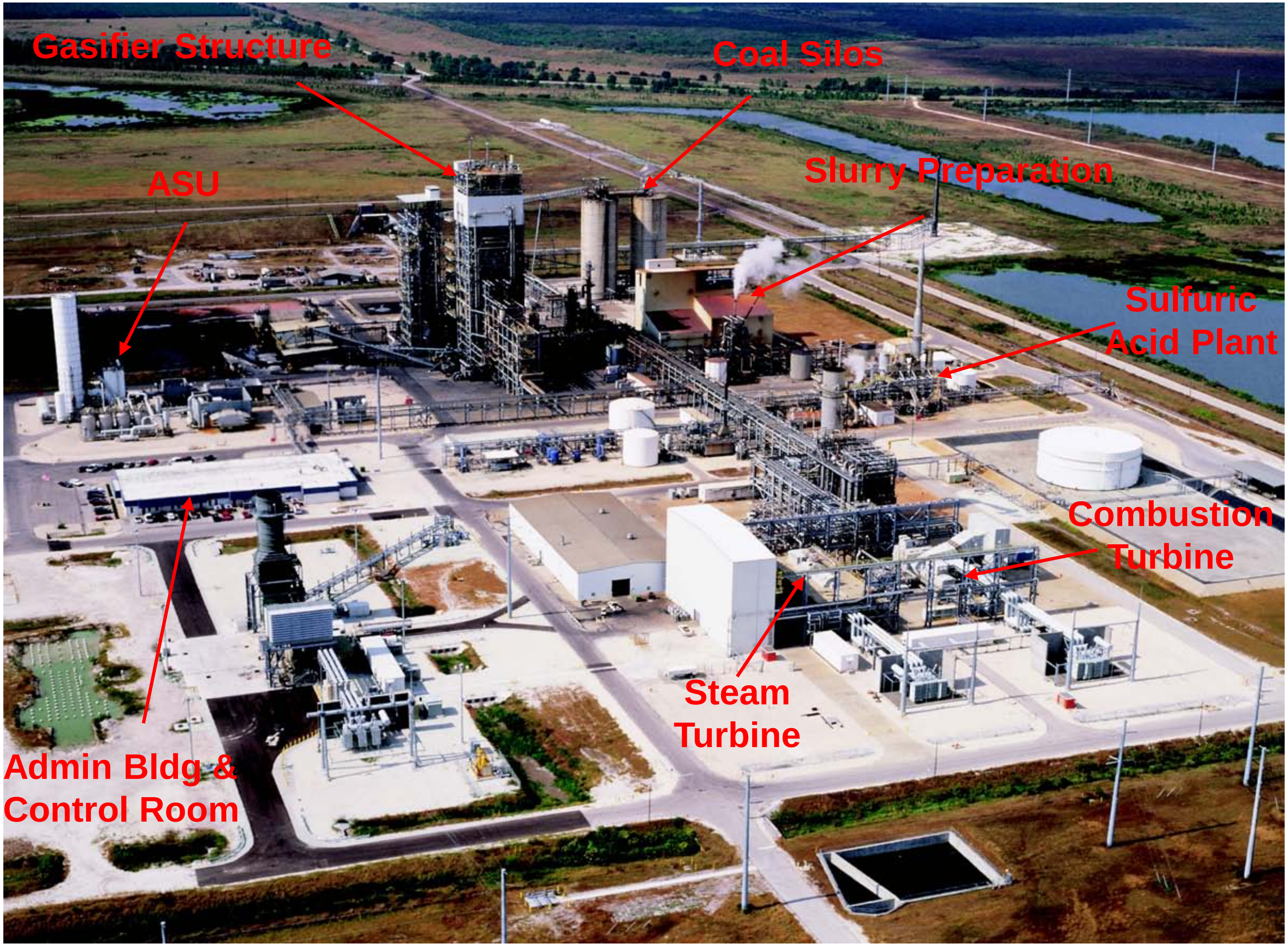
Polk Power Station, Unit

Power generation

Combustion turbine:	192 MWe
Steam turbine:	123 MWe
Internal load:	- 55 MWe
Other auxiliaries:	- 10 MWe
Net output	**250 MWe**

Courtesy: Tampa Electric Co.

Polk Power Station Aerial Photo



Edwardsport 618 MW IGCC Project
Duke Energy

2 x GE Gasifier

2 x GE 7 FB combustion turbines
232 MWe each

GE steam turbine
320 MWe

1.5 million tons of coal per year

Total project cost:
$ 3.5 billion
$133.5 million Federal investment tax credit award
$460 million in local, state and federal tax incentives

Commercial Operations Mid-2013

Gasifier being installed at Duke Energy's Edwardsport Station

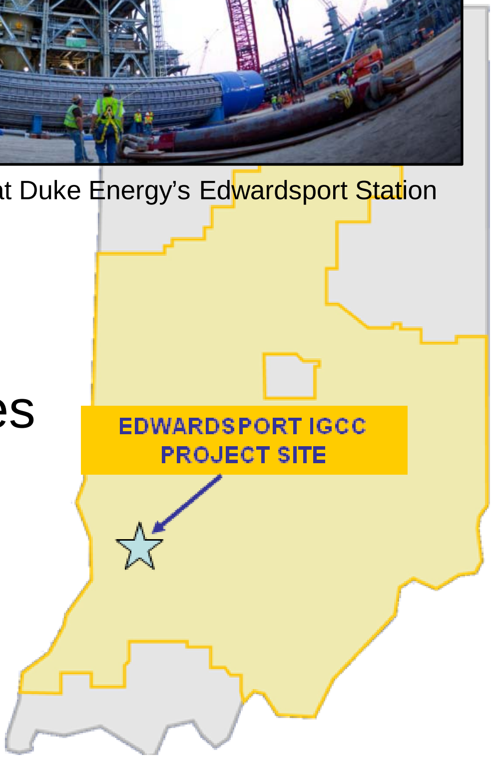


Image courtesy of Duke Energy Indiana

ELCOGAS

Puertollano, Spain

PRENFLO gasifier
Pressurized entrained flow gasifier now offered by Uhde

IGCC Plant Puertollano, Spain

Oxygen blown

2,600 tons/day coal and petcoke

Commercial operation began in 1996 with natural gas

In 1998 began operating on 50/50 petcoke / local Spanish coal (~ 40% ash)

Siemens V94.3 gas turbine

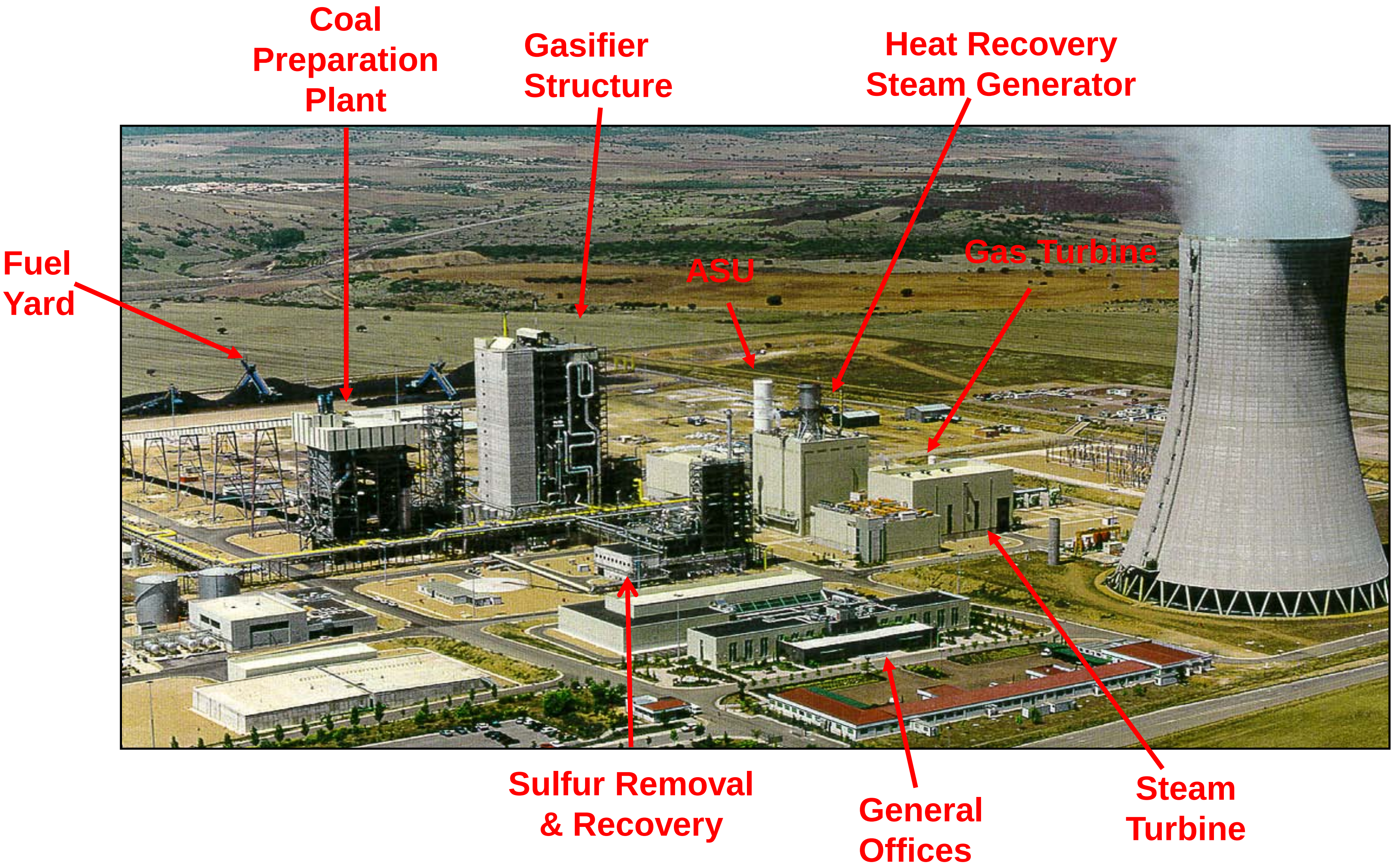
Independent power project without a power purchase agreement (PPA)

Power generation

Combustion turbine	182.3 MWe
Steam turbine	135.4 MWe
Internal load	- 35.0 MWe
Net output	282.7 MWe

Source: "Integrated gasification combined cycle technology: IGCC – Its actual application in Spain: ELCOGAS, Puertollanl" Manuel Treviño Coca
Image Source: www.elcogas.es/shared/enter_img2_r1_c1.jpg

ELCOGAS Plant Aerial Photo



Vresova IGCC Power Plant

Vřesová, Czech Republic

1970 Town Gas Production

1996 Converted to IGCC

26 Lurgi Gasifiers
Entrained flow
Dry coal feed - Lignite

1 Siemens SFG-200
Entrained
Added 2007
Oxygen blown – Full quench
Feedstock: Phenols, tars, petrol, etc. created during gasification

2 GE Combustion turbines
FRAME 9 E (9171 E)

ABB ES Steam turbine

Vřesová IGCC Plant, Czech Republic

Power generation

Combustion turbine:	309 MWe
Steam turbine:	114 MWe
Internal load:	- 25 MWe
Net output:	398 MWe

http://www.gasification.org/Docs/2005_Papers/05CHHO.pdf

Nuon IGCC Plant

Buggenum, The Netherlands

Shell Gasification
Offered jointly with Krupp Uhde

Gas turbine: Siemens V94.2

2,000 tons/day feedstock
Bituminous coal
Biomass

Plant startup 1993

Power generation

Combustion turbine:	155 MWe
Steam turbine:	128 MWe
Internal load:	- 30 MWe
Net output:	253 MWe

Buggenum IGCC Plant

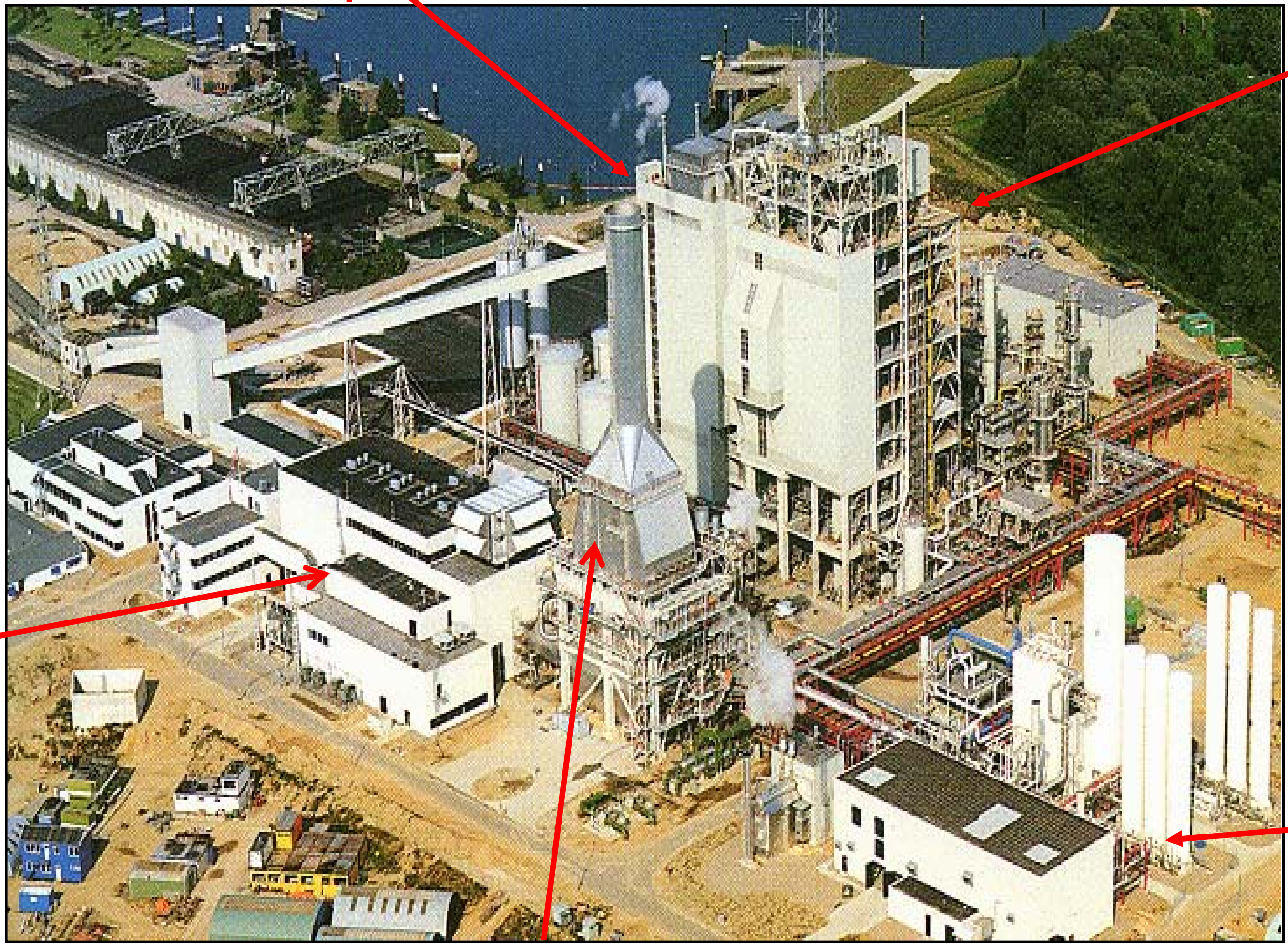
Only large-scale biomass installation in operation today

http://www.gasification.org/Docs/2005_Papers/05CHHO.pdf

Nuon Plant Aerial Photo

Coal Preparation Plant

Gasifier Structure



Gas & Steam Turbine

ASU

Heat Recovery Steam Generator

Note: Sulfur Removal & Recovery (out of view)

Courtesy: Nuon

Clean Coal Power R&D IGCC Demonstration Plant

Nakoso, Japan

Mitsubishi Gasifier
- 250 MWe
- Air-blown
- Entrained flow
- Dry coal feed

1,700 tons/day coal
- Suited to wide range of coals

Water wall structure

Gas clean-up
- MDEA chemical absorption

Plant startup September 2007

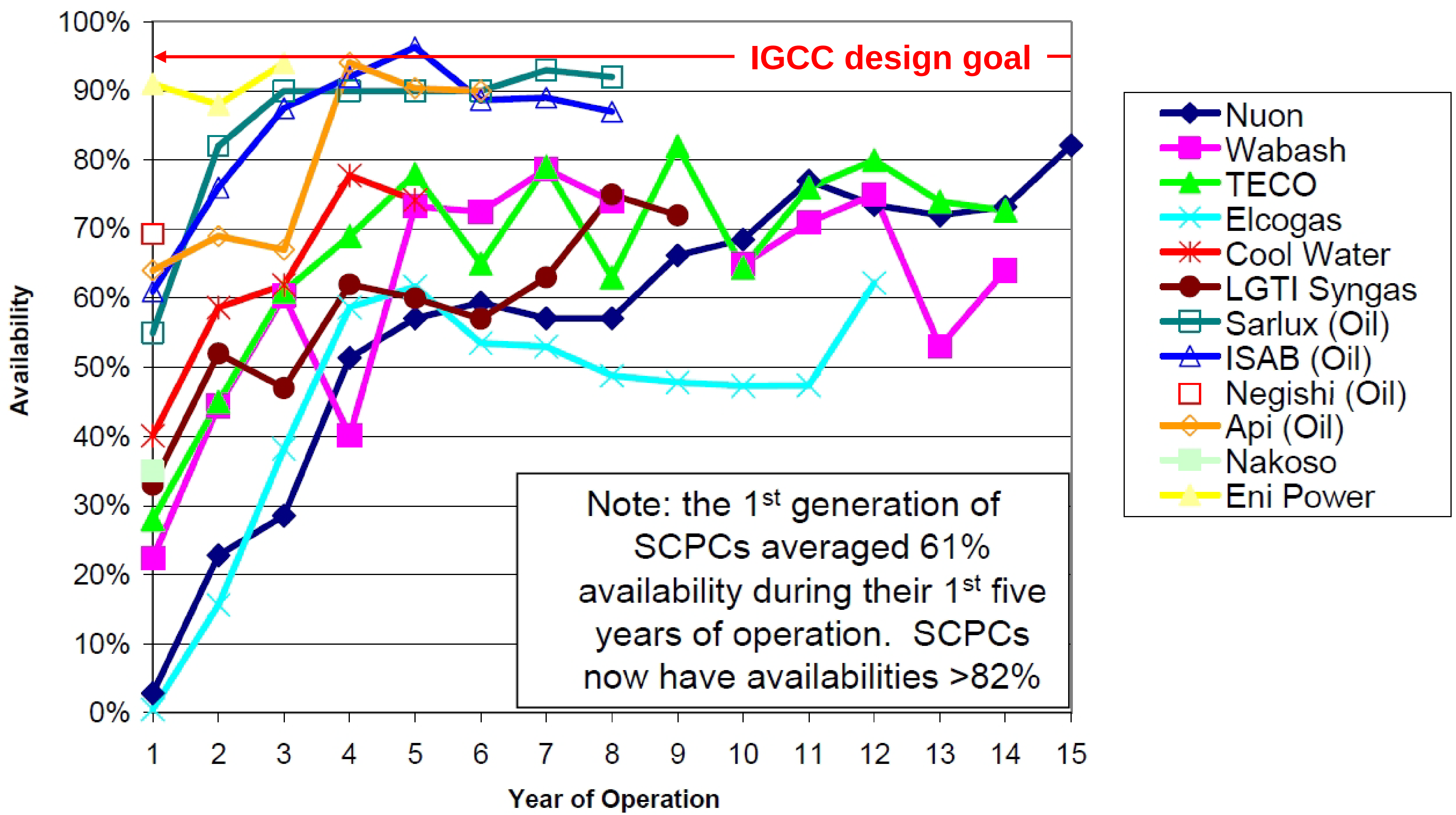
Clean Coal Power R&D Joint project of
- Mitsubishi Heavy Industries,
- Ministry of Economy, Trade and Industry, and
- Several EPC companies

Clean Coal Power R&D IGCC Demonstration Plant

Aerial Photo

Photo: BLOOMBERG NEWS

IGCC Availability History



Excludes impact of operation on back-up fuel

*Source: **Dr. Jeff Phillips** Sr. Program Manager, Advanced Coal, EPRI*
http://www.gasification.org/uploads/downloads/Workshops/2010/02phillips%20-%20IGCC%20101e.pdf

IGCC Plants in the U.S.

No Longer Operating

Southern California Edison's Cool Water Coal Gasification Plant
100 MWe coal (1984-1988)

Dow Chemical's Louisiana Gasification Technology Inc (LGTI) Project
160 MWe coal (1987-1995**)**

Valero Delaware City Refinery's Delaware Clean Energy Cogeneration Project
160 MWe (& steam) petcoke (2002 – 2009)

IGCC Technology in Early Commercialization

Nation's 1st Commercial-scale IGCC plants

Each achieving: > 97% sulfur removal > 90% NOx reduction

Wabash River

ConocoPhillips Gasifier

1996 Power plant of the Year Award*

Achieved 77% availability **

Tampa Electric

General Electric Gasifier

1997 Power plant of the Year Award*

First dispatch power generator

Achieved 90% availability **

Power Magazine*   * Gasification Power Block*

Edwardsport 630 MW IGCC Project

Duke Energy

2 x GE Gasifier

2 x GE 7 FB combustion turbines
232 MWe each

GE steam turbine
320 MWe

1.5 million tons of coal per year

Operational mid 2013 - *in startup*

Total project cost:

$3.5 billion

$133.5 million Federal investment tax credit award

$460 million in local, state and federal tax incentives

Gasifier being installed at Duke Energy's Edwardsport Station

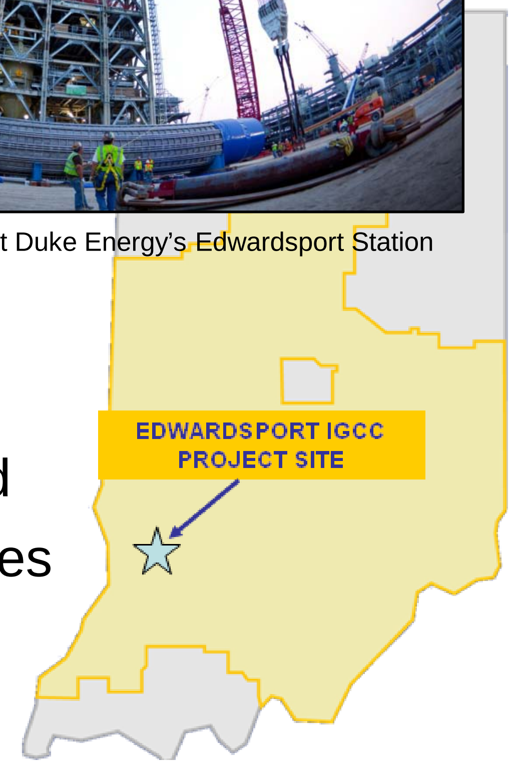


Image courtesy of Duke Energy Indiana

Coal/Petcoke-Based U.S. IGCC Plants

Operational Performance

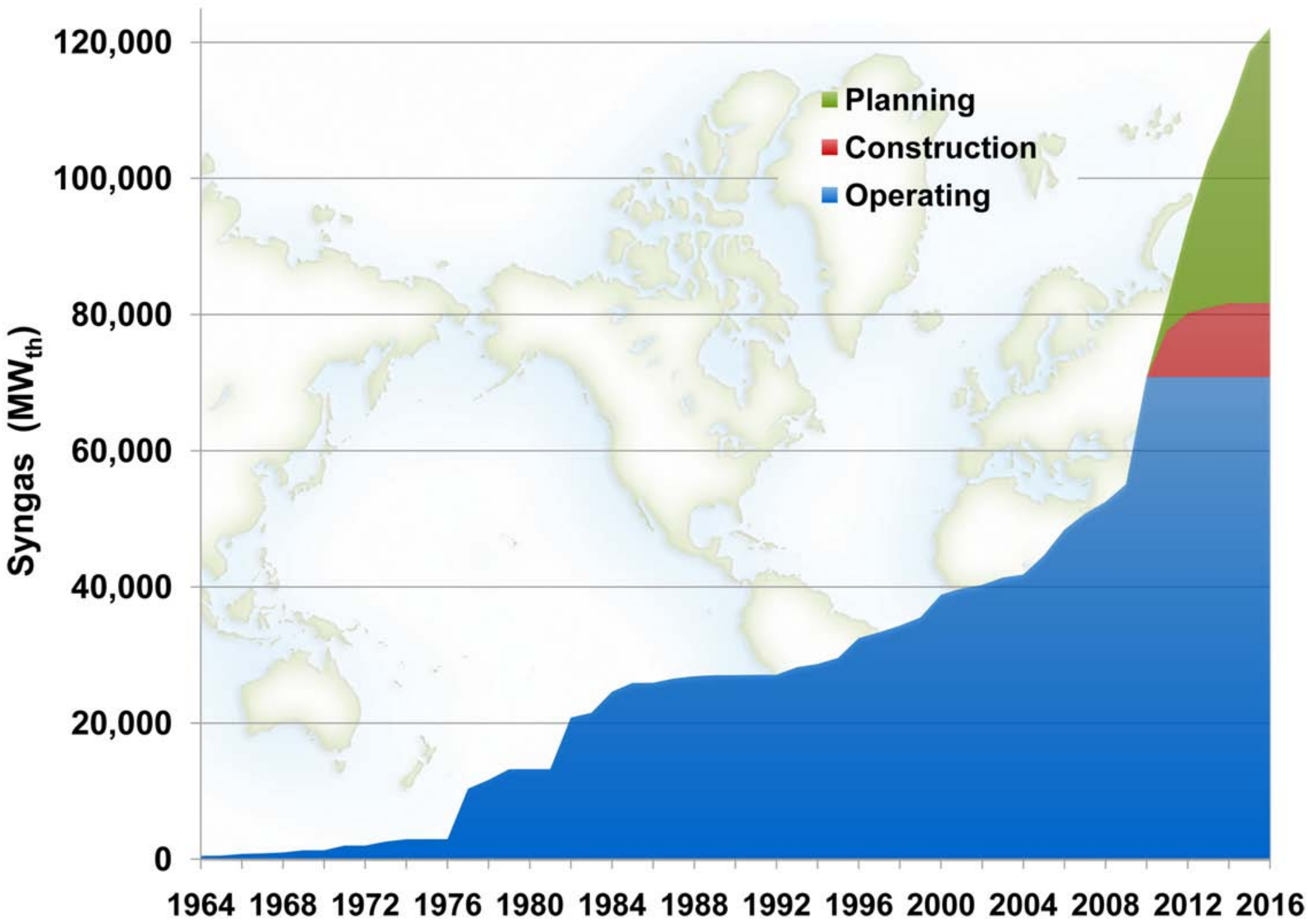
	Cool Water California	LGTI Louisiana	Wabash River Indiana	Tampa Electric Florida	Valero Delaware
Net Power Output MWe	100	160	262	250	240
Efficiency, % (HHV basis)		37.5	40.2	37.5	
Gasification Technology	GE	E-Gas	E-Gas	GE	GE
Feedstock	Bituminous	Low sulfur subbituminous	Petcoke	Coal and petcoke blend	Petcoke
Gas Turbine	GE 107E	2 x Siemens SGT6-3000E	GE 7FA	GE 107FA	2 x GE 7FA
Firing Temp, ˚F (˚C) on natural gas*		2350 (1287)	2350 (1287)	2350 (1287)	
NO_X Control	Steam dilution to combustion turbine	Steam dilution to combustion turbine	Steam dilution to combustion turbine	Nitrogen and steam dilution to combustion turbine	Nitrogen and steam dilution to combustion turbine

** Syngas firing is usually 100-200˚F lower*

Worldwide Gasification Database

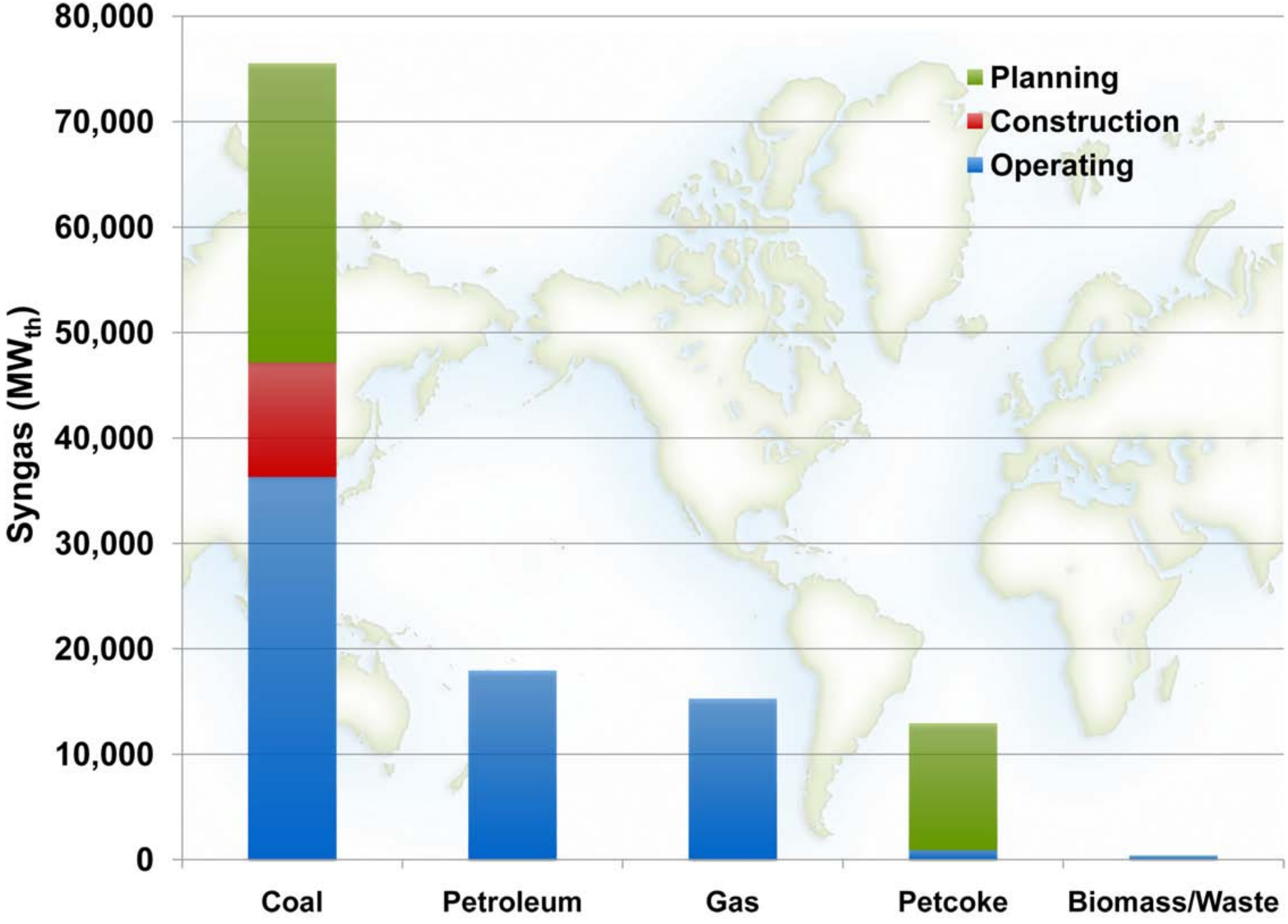
Worldwide Gasification Capacity & Planned Growth

Cumulative by Year



Based on: 2010 Worldwide Gasification Database
http://www.netl.doe.gov/technologies/coalpower/gasification/worlddatabase/index.html

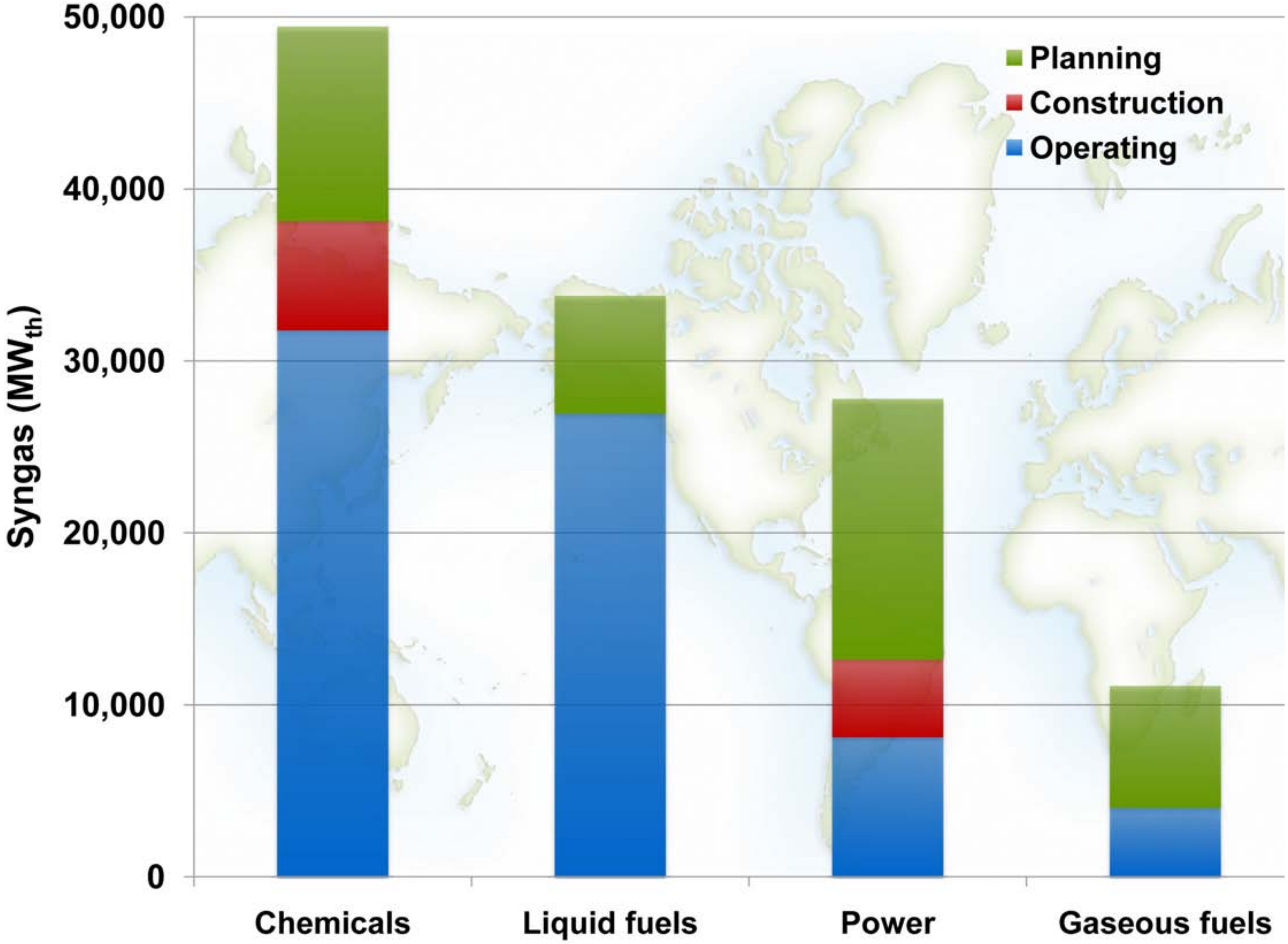
Worldwide Gasification Capacity & Planned Growth
by Feedstock



Based on: 2010 Worldwide Gasification Database
http://www.netl.doe.gov/technologies/coalpower/gasification/worlddatabase/index.html

Worldwide Gasification Capacity & Planned Growth

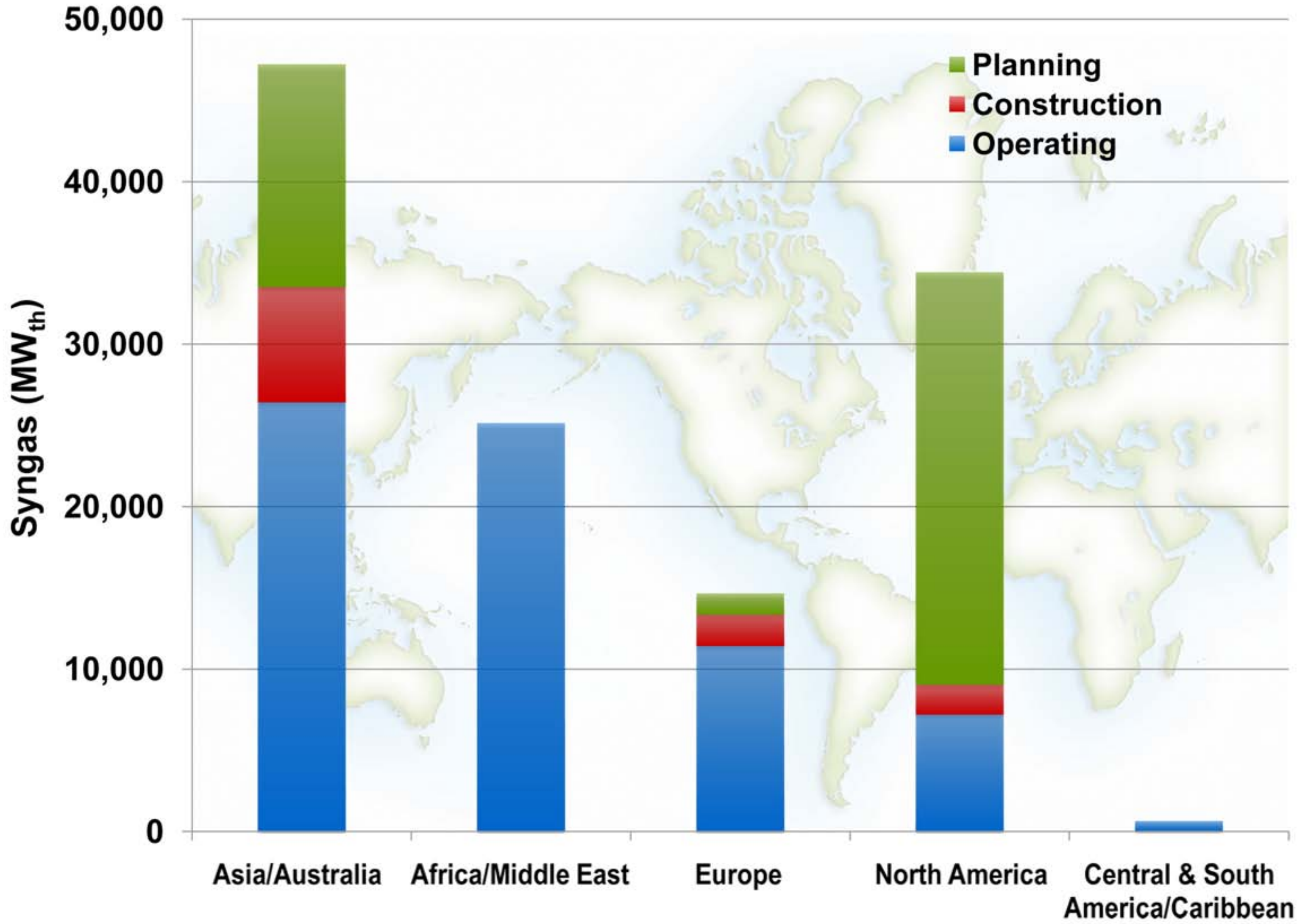
by Product



Based on: 2010 Worldwide Gasification Database
http://www.netl.doe.gov/technologies/coalpower/gasification/worlddatabase/index.html

Worldwide Gasification Capacity & Planned Growth

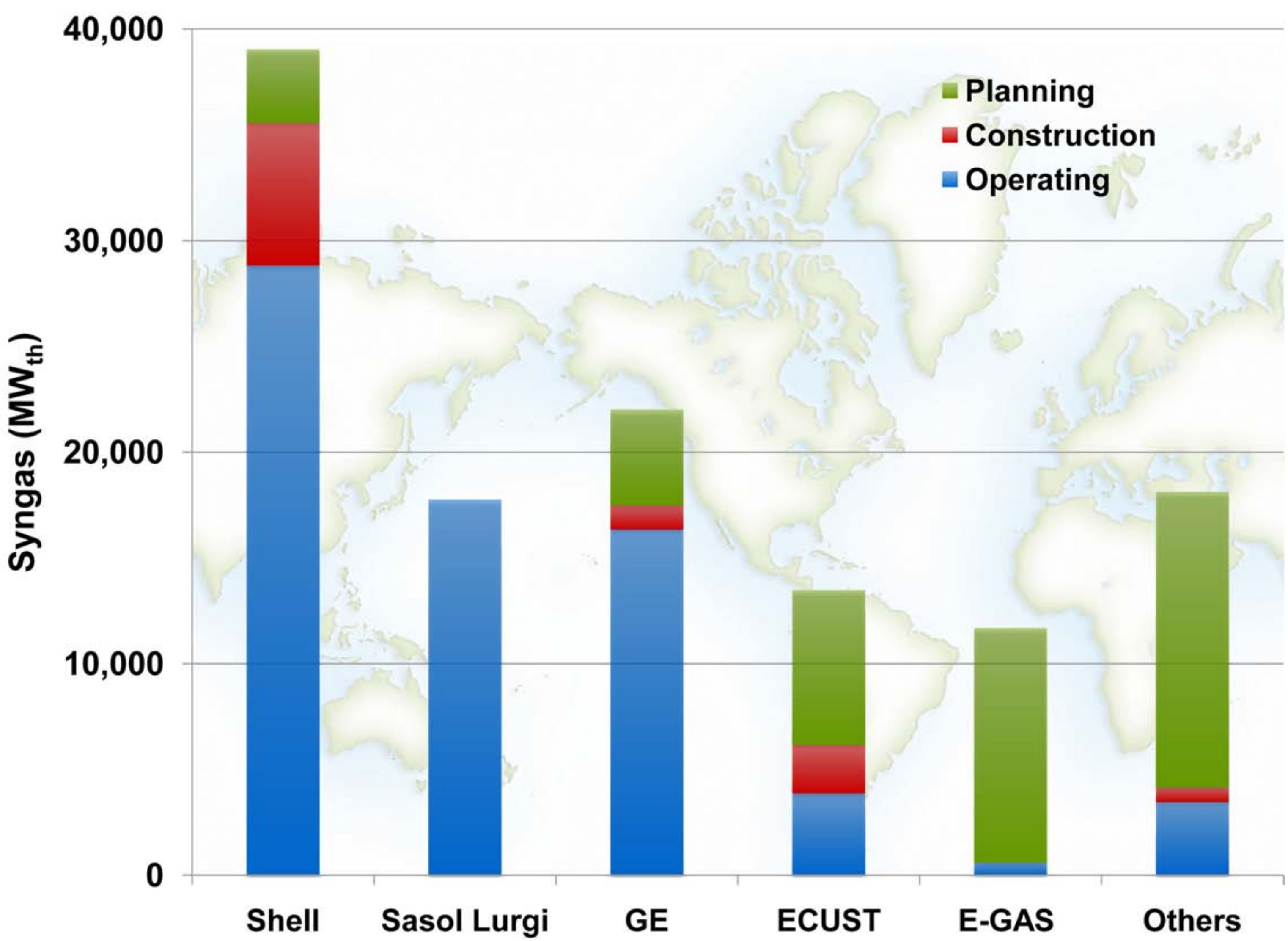
by Region



Based on: 2010 Worldwide Gasification Database
http://www.netl.doe.gov/technologies/coalpower/gasification/worlddatabase/index.html

Worldwide Gasification Capacity & Planned Growth

by Technology



Based on: 2010 Worldwide Gasification Database
http://www.netl.doe.gov/technologies/coalpower/gasification/worlddatabase/index.html

Closing

… the Benefits

GASIFICATION

Stable, affordable, high-efficiency energy supply with a minimal environmental impact

Feedstock Flexibility/Product Flexibility

Flexible applications for new power generation, as well as for repowering older coal-fired plants

BIG PICTURE

Energy Security -- Maintain coal as a significant component in the U.S. energy mix

A Cleaner Environment (reduced emissions of pollutants)

The most economical technology for CO_2 capture

Ultra-clean Liquids from Coal -- Early Source of Hydrogen

Visit NETL Gasification Website

www.netl.doe.gov/gasification-portal.html

Google the term "Gasifipedia" Google Gasifipedia Search